Organizational Characteristics for Successful Product Line Engineering

by

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Abstract

The evaluation of strategic, political, and cultural characteristics at four organizations implementing product line engineering (PLE) was conducted. The objective was to identify non-technical characteristics that attribute to successful product line engineering efforts. A set of questions structured around defined strategic, political, and cultural characteristics was generated for formal evaluation of each organization, and then a series of interviews within each organization was performed to gather case study data. Two of the four organizations studied were identified as being more successful with product line engineering, and, thus, were used as the basis for comparison.

A comparative analysis of the organizations was performed to observe noteworthy characteristics that attributed to success. Some of the key observations include:

- Strategic plans clearly defined goals relating to the development of product lines
- Metrics were used that applied specifically to product line engineering
- PLE strategies were implemented uniformly across the organization
- The smallest percent of projects for each organization utilized the new design strategy
- Organizing resources around platforms, using modular system architectures, and implementing initiatives to standardize components facilitated resource and technology sharing
- By defining and enforcing product line strategies, senior management enabled successful product line engineering

In summary, the study indicated that an organization needs strategic characteristics in place to serve as the foundation from which to implement product line engineering. Senior management (i.e., a political characteristic) is an extension of the foundation largely because it defines the embodied strategy and enforces it. It is imperative for senior management to provide the power and resources that will enable a product line engineering culture – it is the primary link from strategy to culture. The cultural characteristics are the means by which strategies and goals are implemented and product development is executed. A PLE culture will not succeed if a strategic foundation and a political constituent do not fundamentally uphold it.

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This thesis is dedicated to the memory of my friend and colleague, Rob Northrop (SDM98), with whom I had numerous conversations about platforms and product lines.

Acronyms

CAE	Computer Aided Engineering
CCB	Change Control Board
CEO	Chief Executive Officer
COTS	Commercial-of-the-Shelf
CTR	Cycle Time Ratio
GM	General Manager
PDP	Product Development Process
PLE	Product Line Engineering
RSP	Risk Sharing Partners
R&D	Research & Development
SBE	Strategic Business Enterprise
STRAP	Strategic Plan
TQM	Total Quality Management
VOC	Voice of the Customer
VP	Vice President

1.0 Introduction

1.1 Problem Statement

In recent years, there has been an increasing demand in the aerospace industry to reduce the time and money it takes to develop a new system or product. To address that demand, there have been several successful initiatives such as “total quality management” (TQM), “six sigma”, and “lean enterprise”, which have made improvements in the area of product development. However, the challenge still exists to make further progress. Initiatives utilizing “reuse”, “commercial-off-the-shelf” (COTS) products, and “product line engineering” have emerged from the consumer electronics and automobile industries and show great potential for influencing additional product development enhancements in the aerospace industry. Although there have been successful applications of reuse, COTS, and product lines [1, 2, 3], these practices are by no means easy to accomplish, especially in the aerospace industry.

Traditionally, the aerospace industry has developed unique systems for one customer. More often than not, that “customer” has been the United States government. As the defense budget continues to decrease, the government is looking to industry to find more efficient methods by which to develop its systems. The aerospace industry has no choice but to respond to this request – and it is likely that contracts will be awarded to the companies that most effectively and quickly implement solutions. One way to decrease cost is to distribute it over several customers or markets; likewise, one way to decrease development time is to reuse already proven technologies and components. Thus, one solution to the problem outlined above is for the aerospace industry to utilize product line engineering. The theory behind product line engineering is to develop a platform architecture from which several derivative products can evolve. The derivative products form a product line, which, as a whole, can address the needs of several different market segments.

Making a transition to product line engineering will require organizational change as well as technical change. If a company is prepared organizationally to implement PLE, then it may be easier to incorporate the necessary technical/product changes. The organizational aspects of a company provide a basis upon which technical operations can thrive. Hence, with sufficient organizational characteristics defined, a product line engineering initiative has a better opportunity to succeed. If a company is considering the implementation of PLE, then it should begin by establishing the organizational characteristics to facilitate success. Therefore, the question is –

- What organizational characteristics attribute to successful PLE applications?

1.2 Thesis Structure

This thesis proposed to answer the question expressed in the problem statement. The structure of the thesis is described below:

- Section 2.0 provides a general background on product line engineering, the benefits, and the disadvantages; then describes the strategic, political, and cultural organizational characteristics impacted by product line engineering.
- Section 3.0 describes the research objective and methodology, the companies interviewed, and the interview process.
- Section 4.0 consolidates the interview data into four individual case studies.
- Section 5.0 presents the results that emerged from comparing the four organizations on a point-by-point basis and discusses the observations in some detail.
- Section 6.0 provides a summary of the observations and makes recommendations based on the strategic, political, and cultural perspectives of an organization for those planning to implement product line engineering.

2.0 Product Line Engineering

The definition of product line engineering, as used in this thesis, is as follows: the discipline of developing product lines, where a product line is a group of products developed from a platform architecture or platform product[1] that meets the needs of several different market segments. A platform architecture consists of a core set of functionality or components from which several derivative products can be developed.

Developing a platform architecture can be a lengthy, involved, and intricate process, but once it is developed, generating the rest of the product line should not require as much time or money. Marketing and engineering must work closely to develop a strategy from which to operate. Marketing needs to analyze the market, document the needs of the customers, and segment the market. Once the voice of the customer (VOC) is known, the needs that are the same across market segments must be identified. These needs will most likely translate into requirements for the platform architecture.

Product line engineering is a strategy that organizations can implement to take advantage of the potential benefits, such as reduced lifecycle time and cost. First an organization must define a product line engineering strategy and then put the organizational attributes in place to implement it.

2.1 Platform Architectures

Platform architectures are the foundation of product lines. Meyer and Lehnerd [4] define a platform architecture (or in their words a "product platform") as "a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced" (p. 39). A modular design or architecture is inherent to platforms.

2.1.1 Modularity

Modular architectures as defined by Ulrich and Eppinger [5] have the following two properties (p. 132):

- Components implement one or a few functional elements in their entirety.
- The interactions between components are well defined and are generally fundamental to the primary functions of the product.

[1] Henceforth, platform architecture and platform product will be used interchangeably.

There is a significant amount of benefits associated with using a modular architecture. The foremost advantage is module or component reuse. A modular design promotes reuse or component sharing within a product line as well as across product lines. When a component is reused in several products, there is potential to achieve economies of scale, which are not typically realized in the aerospace industry. In addition, cost savings are realized because development costs and capital investments are amortized over several products rather than one product. Ulrich and Tung [6] referenced six different types of modularity: component-sharing, component-swapping, fabricate-to-fit, mix, bus, and sectional. Figure 1 [7] depicts these six types of modularity.

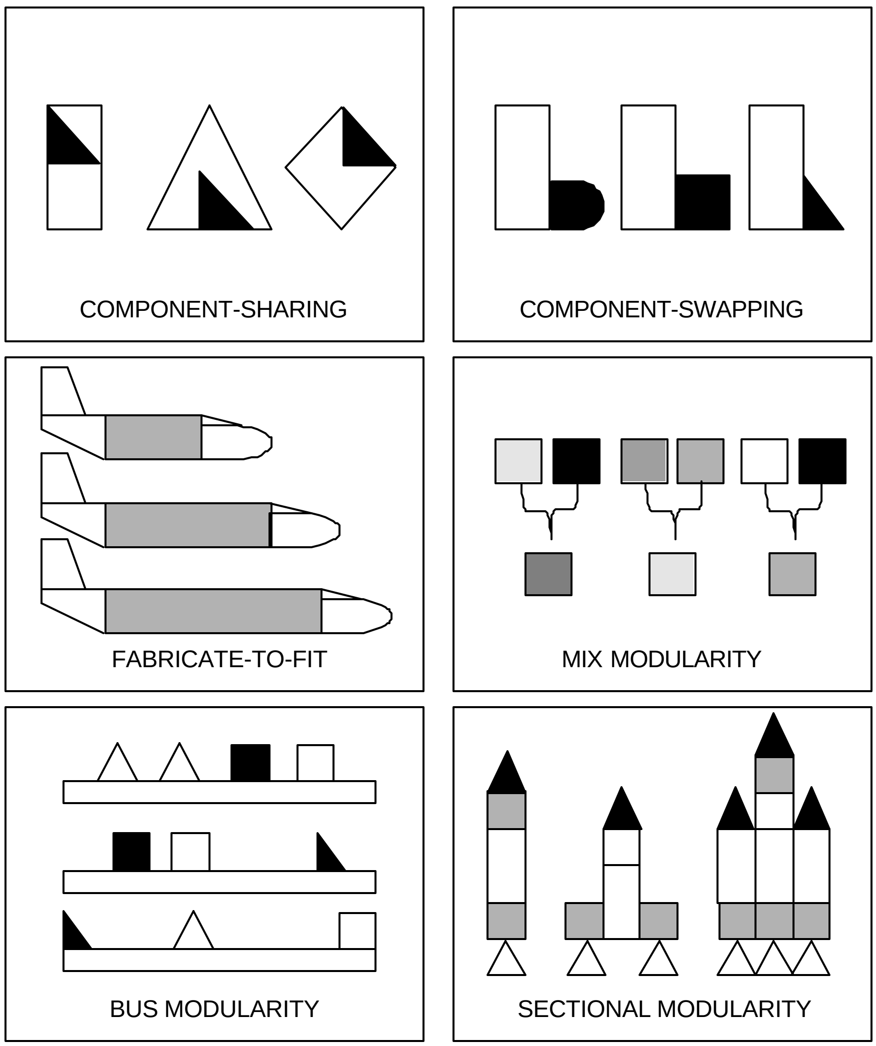

Figure 1 – Six different types of modularity [7]

It is assumed that product line engineering could utilize any of these identified types. Another potential benefit of a modular architecture is that it facilitates a clear division of work, which could result in increased accountability by the module owner and/or development team. For some components, this division of labor may also lead to an acquired specialization. For example, a team working on a redundancy management component may become experts in this area. Lastly, a modular architecture can better facilitate technology upgrades compared to an integral architecture by limiting change to a specific module rather than an entire design or subsystem. Modularity can be recognized as the characteristic that provides most of the benefits associated with platform architectures and, thus, product line engineering.

Unfortunately, there are also several disadvantages associated with achieving a modular system. First, it is very difficult to design a modular architecture for optimal system performance. Finding the right division of functionality can sometimes be complex, and, typically, an integral architecture can provide increased performance over a modular architecture. Second, because a modular architecture is difficult to design, it may require more effort (i.e., planning and resources). Although *designing* a modular architecture may require more effort, as previously mentioned, the individual *development* effort of a module is actually facilitated. The third disadvantage, however, can result from individual module development. If communication is ineffective between module development teams, then the interfaces may not be correctly constructed and, thus, the integration effort will suffer (i.e., more debugging and rework; hence, more schedule and budget overruns). Although there are identified disadvantages to modularity, in most cases the benefits outweigh them. Furthermore, employing knowledgeable system architects, performing proper planning, and ensuring good communication (i.e., proper management oversight) within and between development teams can overcome most of these barriers.

2.1.2 Integrality

If a design is not primarily modular then it may be considered integral. Platform architectures can implement integral designs, however, component reuse will be less likely. Integral architectures may demonstrate one or more of the following properties (Ulrich and Eppinger p. 133):

- Functional elements of the product are implemented using more than one component.

- A single component implements many functional elements.
- The interactions between components are ill-defined and may be incidental to the primary functions of the products.

Like modular architectures, integral architectures have both benefits and disadvantages. The most significant benefit of an integral architecture is the potential for optimal system performance. Integral architectures also require fewer components and, consequently, fewer interfaces. The reason for fewer components is that several functions may be implemented by one component, which ultimately creates the disadvantages. Since integral architectures distribute functionality across more than one component, it is more difficult to clearly define development responsibility and accountability. In addition, integrality limits reuse. The integral design may result in "specialized" rather than "standardized" components that are not easily shared across product lines. Finally, technology upgrades for integral architectures may require extensive rework of the design.

2.1.3 Modular versus Integral Architectures

Ulrich and Eppinger [5] state that products are rarely strictly modular or integral. Instead, a product may be more modular than integral or vice versa. When trying to determine whether to design a primarily modular or integral architecture, an architect needs to consider many factors. For example, is the product being developed with the need for optimal performance or extensibility? Platform architectures for product lines are primarily modular to facilitate reuse, extensibility, flexibility, and upgrades. An integral architecture could be used as well; however, modular architectures can better facilitate product line development. In their book *Thinking Beyond Lean* [1], Cusumano and Nobeoka illustrate the increasing importance of utilizing platforms in the automotive industry. In other industries as well, such as the aerospace industry, the importance of using platforms is becoming more apparent. Regardless of the type of architecture selected, it is critical to take sufficient time to generate the platform when executing product line engineering.

2.2 Benefits

Researchers [1, 3, 4, 8, 9] have documented the potential benefits resulting from a product line engineering strategy. More specifically, these benefits can be associated with platform architectures, which are the foundations of most product line engineering efforts.[2] This section will describe, in more detail, the benefits associated with product lines.

The most widely known benefits of utilizing a product line engineering strategy are reduced development cycle time and costs for follow-on products [1, 8]. CelsiusTech Systems AB, a Swedish company, provides a notable example of a naval defense contractor that has successfully implemented product line engineering for large, complex, software-intensive systems, and, hence, achieved some of the potential benefits [3]. As with the case of CelsiusTech, though, these benefits are typically not realized in the short term. Product line engineering is a long-term strategy that takes a strong commitment from senior management to implement. It took CelsiusTech nine years (from 1986-1995) to develop the platform product in its Ship System 2000 (SS2000) product line (although functional releases were being field tested after three years). The next set of derivative products in the product line was developed in about five years, while the final two products only required two years to develop. On average, 70-80% of the derivative products consisted of reused components (no modification). When proper planning is done for a product line and, thus, a platform architecture, then the reduced development time and cost benefits can be almost assured for subsequent products. As discussed for CelsiusTech, the reductions in time and cost are achieved by leveraging previously designed and developed components of the platform product/architecture. Another benefit of leveraging previously developed components, which CelsiusTech as well as other organizations have experienced, is less technical uncertainty for derivative products [3, 8]. CelsiusTech also benefited from increased cost and schedule predictability. CelsiusTech reported building its asset base for reuse through product line engineering. These reusable assets included hardware and software technologies along with non-technical items, such as work breakdown structures and documentation.

The structure of a product line engineering organization can also facilitate organizational learning and sharing [1] and, consequently, cost and time benefits.

[2] Henceforth, when I speak about a product line I mean a product line that was developed from a platform architecture. Therefore, product lines subsume the benefits of platform architectures.

When an organization is structured to support product line engineering, then there is a greater potential to share resources (i.e., people, hardware, etc.) between projects in the same product line because of the commonality. Personnel can also be transferred from one product line to another to promote reuse across product lines as well as organizational learning. The Toyota Motor Corporation was able to achieve the reduced cost and development time benefits of developing product lines after reorganizing the organization around automotive platforms (i.e., development centers – discussed in more detail in later section) to take advantage of resource and technology sharing [1]. From 1992-1993, Toyota reorganized its personnel into development centers, which, among other things, maximized the opportunity to share components across product lines. By 1994, for an average project, Toyota was reporting a 30% reduction in development cost and a reduction in lead times on the order of a few months. Toyota attributes these performance changes to increases in component sharing, simultaneous engineering, and a reduction in the number of required prototypes. For an average project, it achieved a 40% reduction in the number of required prototypes, which it attributed to “intensive coordination between different engineering and testing functions” as well as increased Computer Aided Engineering (CAE) usage. All of these benefits were reported as a result of Toyota’s reorganization.

Although there are several benefits to product line engineering, there remain some disadvantages or obstacles to overcome. All things considered, however, the price an organization has to pay to overcome the obstacles can be worth the rewards associated with successful product line engineering.

2.3 Disadvantages

Most of the disadvantages stem from the need to design and build a platform architecture, especially when the platform is modular as previously discussed. Since a platform architecture serves as a foundation for several follow-on products in a product line, it takes a significant amount of time to plan the product line and develop the platform architecture. Therefore, the preliminary development costs are exceptionally high [1]. In other words, it will take a lot more time and money to develop the platform architecture compared to the rest of the products in the product line. Brownsword and Clements reported [3] that it took CelsiusTech nine years to develop the first two products in their *SS2000* product line. Approximately two out of the nine years were spent developing the platform product, which ultimately accounted for about one-third of the initial investment. CelsiusTech found, however, that its unyielding approach paid off when the derivative products took just five and then two years to develop. Reiterating what has already been stated, if the platform is well planned, designed, developed, and managed, then the potential rewards of the following product line will be worth the investment.

Another disadvantage to developing a product line is that the platform architecture has higher complexity compared to non-platform architectures [8]. One reason for higher complexity is that, technically, the platform is being developed with derivative products already planned and the architecture must take these products into account. When a system architecture is being developed for a single system, trade study analyses can be made for the single system and the architecture can be more easily optimized for the single system than if the architecture had to be optimized for a series of systems or products. Organizational and financial considerations also add to the complexity. For example, some organizations may find it troublesome to justify the allocation of pre-determined budgets and resources to the platform project when it is not going to provide a return on investment in the short term.

Although a product line may have higher market potential than a single product, the overall technical performance of platform products is lower relative to non-platform [5, 8]. Technically, modular architectures are not as optimally designed for performance, as are integral architectures. For example, incorporating two or more functions into one component might optimize an integral architecture. In the case of weight performance, this can make a substantial difference.

Lastly, implementing a “change initiative” or making a technology transition within an organization can result in reduced effectiveness during the transition period. Progressing to a product line engineering organization is no exception and will take time as well as an initial investment, and may result in reduced productivity for a period of time. Brownsword and Clements [3] did not divulge the investment expense that CelsiusTech made to successfully convert the organization to product line engineering, however, they stated that the actual costs “were by any means intimidatingly large” (p. 68).

2.4 Organizational Characteristics

The case study [3] of the Swedish naval defense contractor, CelsiusTech, suggested that the non-technical issues associated with product line engineering are at least as critical as the technologies involved. There are multiple ways to view the non-technical aspects of an organization. Ancona, et al, describe three perspectives on an organization that have been developed over the years – the strategic perspective, the political perspective, and the cultural perspective [10]. Each of these perspectives provides a distinct way to observe an organization and, thus, provides a well-rounded approach to analyzing an organization. These three perspectives serve as a framework for the study of organizational characteristics that attribute to product line engineering. The organizational characteristics researched in this thesis are categorized by one (or more) of these perspectives. The following sections describe, in detail, each characteristic associated with the perspectives.

2.4.1 Strategic Perspective

2.4.1.1 Goals

Every organization has strategic goals. Senior management spends a significant amount of time identifying these goals and planning how the organization is going to meet them. It is absolutely necessary that both the strategic goals as well as the planned methods of achieving the goals be communicated to the entire organization. In order for an organization to make a transition to product line engineering, it is imperative for senior management to understand the rationale behind such a strategy, believe in it, and clearly communicate it to the entire organization. CelsiusTech [3] credits its management for leading them through the chaos during the initial transition years. Senior management’s vision and focus were vital to CelsiusTech’s success. An organization considering the implementation of product line engineering needs to identify goals that reinforce the initiative. Furthermore, a product line engineering approach facilitates strategic planning by forcing an organization to look ahead and understand what direction it is heading.

2.4.1.2 Structure

Once an organization has established a product line engineering strategy, it needs to strategically arrange its people to facilitate communication among teams and coordination of tasks. The organizational structure should be aligned with the business objectives and development strategies; it should be suited to the organization's capabilities. In the past, the most common organizational structures have been "functional", "product", and "matrix".

A typical functional organization arranges personnel by their respective function (i.e., engineering, marketing, etc.). The functional managers assign their personnel to projects, and are responsible for the performance, evaluation, and development of them. Personnel from each functional department are distributed to all of the development projects. The advantage of this type of structure is the potential to develop organization specialists in the respective functions. However, disadvantages also exist. One problem observed with this type of structure is a communication breakdown between functional groups, which leads to interface issues. When personnel are organized functionally and then put onto a project, they tend to work independently and optimize design for their particular function rather than consider the whole system, and design to optimize the system. Not only does this make system integration difficult, but it also affects the system's performance. A graphical representation of this organizational structure can be seen in Figure 2.

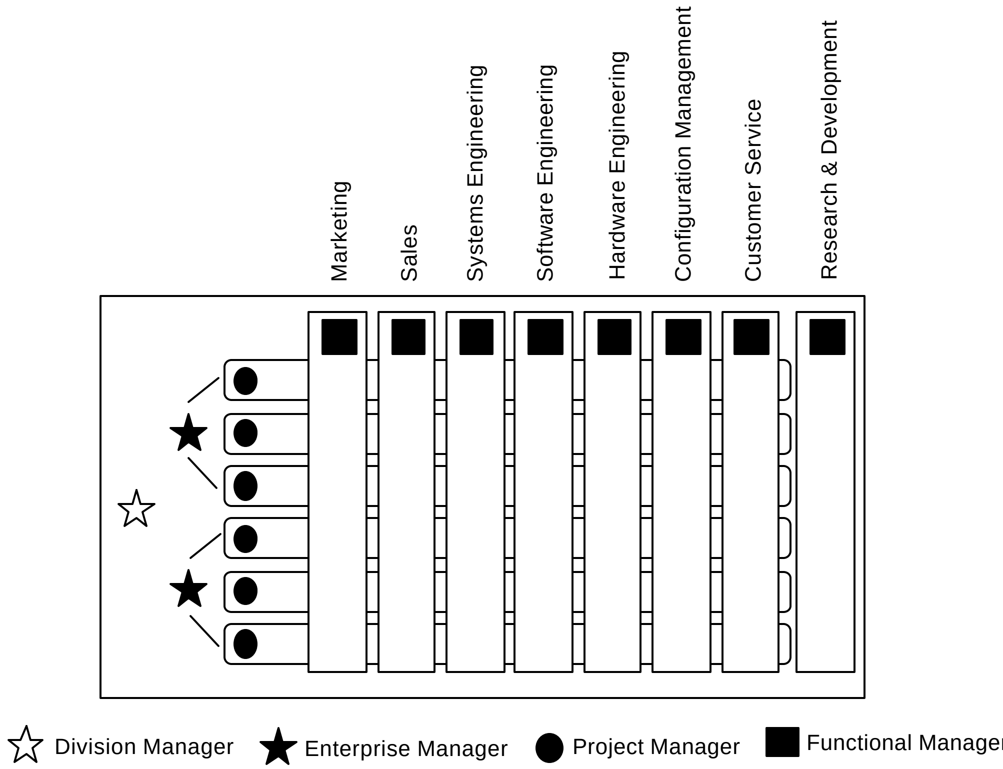

Figure 2 – Functional Organizational Structure

In a product organization, personnel are organized into groups based on product types, and only report to project managers. Each project concentrates on developing one product (see Figure 3). Projects developing similar products may be grouped into separate businesses.

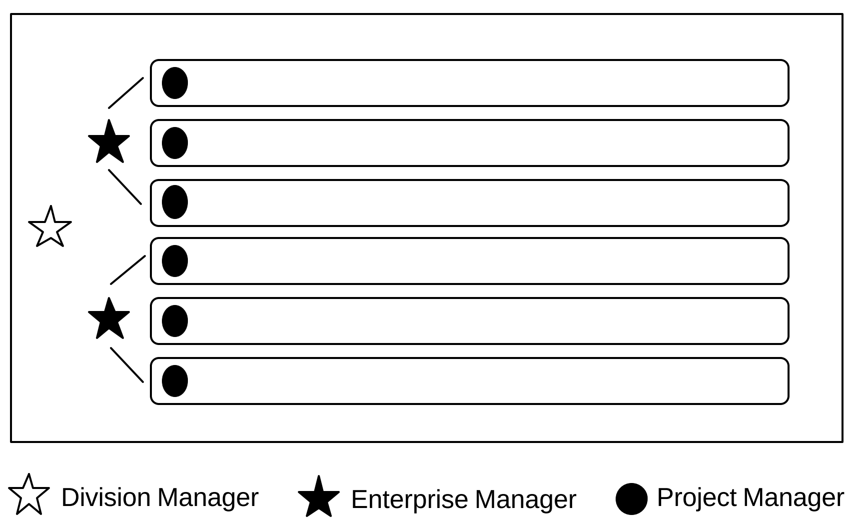

Figure 3 – Product Organizational Structure

Typically, resources such as information technology management and human resource management are shared between businesses, while engineering, manufacturing, and marketing are maintained separately by each business. The primary advantage of such a structure is that each business enterprise can operate autonomously and, thus, organize itself to meet the demands of its market segment. However, the disadvantages are redundant resources and lack of technology sharing and organizational learning.

Lastly, in a matrix organization, personnel are organized by both function and product. Each employee in a matrix organization reports to a functional manager as well as a project manager. Theoretically, the functional and project managers share an equal status or power. Problems with the matrix organization arise, however, when one dimension becomes more powerful than the other [10]. When this happens, personnel find it perplexing to report to both managers. A graphical representation of a matrix organization can be seen in Figure 4.

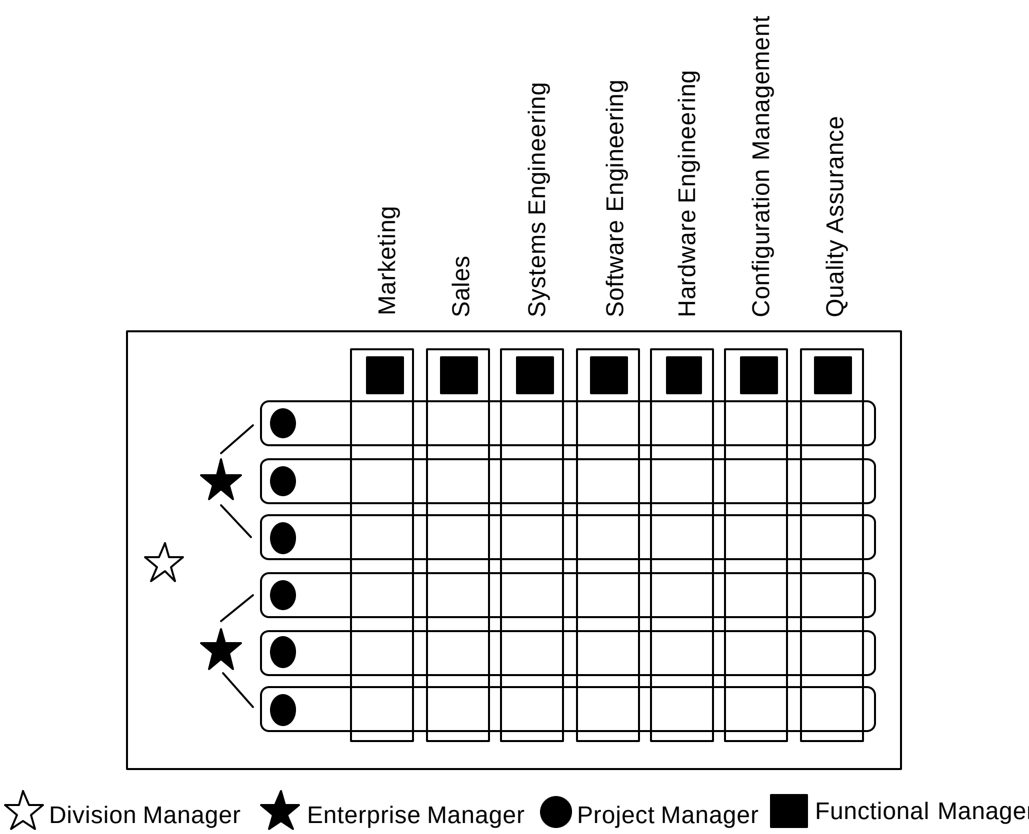

Figure 4 – Matrix Organizational Structure

When talking to most people in industry, they will, typically, state that for some period in time their organization was structured like each of the above mentioned structures. As a matter of fact, if someone works in an organization long enough, a cyclical restructuring of the organization can be experienced. It seems that the restructuring frequency can happen as often as every 2-3 years. Organizations continuously evolve and change in order to adapt to current demands and competition. It would be ludicrous to propose that organizations adopt a structure and not evolve to adapt to their changing environment because change is inevitable. On the contrary, it would not be ludicrous to propose that organizations embody a flexible structure that can adapt to changing environmental demands and technologies without requiring restructuring. It would even be beneficial if a flexible structure at least increased the period between organizational restructuring.

Most organizations have used either the functional, product, or matrix structures to manage the development of their products in isolation. In other words, each product is developed individually and not strategically to achieve resource and technology sharing. In the case study of CelsiusTech, which was previously mentioned [3], it was stated that the simultaneous awarding of two different contracts is what prompted CelsiusTech to shift to product line engineering. Upon award of the two contracts, CelsiusTech evaluated its business and technical approaches and concluded that its current strategies were not sufficient to develop the two products in isolation. In fact, it did not even have the personnel required to maintain individual product development efforts. This particular problem compelled CelsiusTech to adopt a new business and development strategy where it could, at minimum, share resources and technologies – thus, the organization adopted a product line development strategy. Essentially, when an organization is implementing product line engineering, it is managing multiple projects at one time, trying to maximize reuse and minimize development cost and time. As a result, the organization needs to adapt an organizational structure that facilitates these strategic goals.

Cusumano and Nobeoka suggest that organizations stop developing products in isolation and concentrate on multi-project management [1]. Here is what they say about multi-project management:

> “To us, the primary strategic issue is to what extent managers want to utilize the technology as well as other knowledge or capabilities their firm has already accumulated in past projects. This other knowledge can take the form of how to organize and manage projects as well as engineering work more rather than less effectively. The concept of multi-project strategy and management, therefore, requires a linkage between technology and organization. It emphasizes the leveraging of accumulated firm-level resources and capabilities.” (p. 103)

Although their studies focus primarily on the automotive industry, they recommend multi-project management for any company that makes more than one product.

From the extensive study of Toyota documented by Cusumano and Nobeoka [1], it is known that Toyota transformed its organization into a hybrid structure called “development centers” during 1992-1993, specifically to concentrate on a multi-project management strategy. During the years that led up to the reorganization, Toyota was actually ahead of its competition. Top executives at Toyota, however, believed that they needed to review the organization and overhaul it so that Toyota would remain competitive in the year 2000. The transformation from a matrix organization to development centers was the result of a study of its product development organizational structure and processes.

Shortly after the review initiative began, the consulting team hired to do the study identified two problems that would require Toyota to overhaul its organizational structure and development strategy. Basically those problems were decreasing efficiency of internal communications and coordination of tasks in product development, and decreasing competitive advantage. Prior to the reorganization that began in 1992, Toyota’s product development was arranged as a huge matrix organization, where functional managers and product managers (called *chief engineers* at Toyota) roughly had equal power. Chief engineers, though, were responsible for the entire product development effort for a particular product and found it difficult to coordinate all of the functional departments. The matrix organizational structure had worked for Toyota previously, but over the past fifteen years Toyota had grown in size to the point that a matrix structure was no longer optimal. In 1991, just prior to the reorganization, a chief engineer had to coordinate people in 48 departments in twelve divisions to launch a new product development effort. Fifteen years before that, a chief engineer only had to coordinate people in 23 departments in six divisions. The growth of Toyota had made internal communication and coordination of tasks for product development extremely complicated and, in short, inefficient. In addition to the predicaments that the chief engineers were experiencing with new product development, the growth of the organization also impacted other staff positions. For example, functional managers found it difficult to oversee their personnel working on 15 various projects and, thus, coordination of technology sharing among projects was almost impossible. Furthermore, because there were so many functional divisions, the engineers became increasingly specialized and focused in their particular area and, hence, lost their system perspective or "holistic view" [1]. Although the matrix organization was no longer sufficient for Toyota, Cusumano and Nobeoka reported that Toyota did not believe that a product-aligned structure was adequate, partly because of the large number of projects simultaneously ongoing. In addition to the problems created, in part, by the outdated organizational structure at Toyota, the strong competitive advantage that Toyota once enjoyed was diminishing. For various reasons, one being the appreciation of the yen, product development cost became more important than in the past. It was imperative that Toyota shift the focus from optimally developing individual products one at a time to optimally developing multiple products (i.e., multi-project management). Because of the changes that were transpiring within Toyota, as well as within the automotive industry, Toyota needed to find a suitable organizational structure and development strategy that would take it into the 21st century. Toyota believed that development centers would address the variant issues; hence, it transformed the organization during the period of time from 1992-1993 [1].

Development centers, a term presumably coined by Toyota, focus around common platforms. In the case of Toyota, its three primary centers focus on front-wheel drive platforms and vehicles, rear-wheel drive platforms and vehicles, and utility vehicle/van platforms and vehicles. Toyota examined the possibility of aligning the centers by other groupings such as market/product segments (i.e., luxury versus economy vehicles), but concluded that organizing the centers around product platforms would best facilitate technology sharing [1]. Toyota's development center structure is slightly different than the more traditional structures like the functional and product organizations. Moreover, development centers could possibly be considered a hybrid of the product and matrix organizational structures. A depiction of Toyota's development centers can be seen in Figure 5 [1].

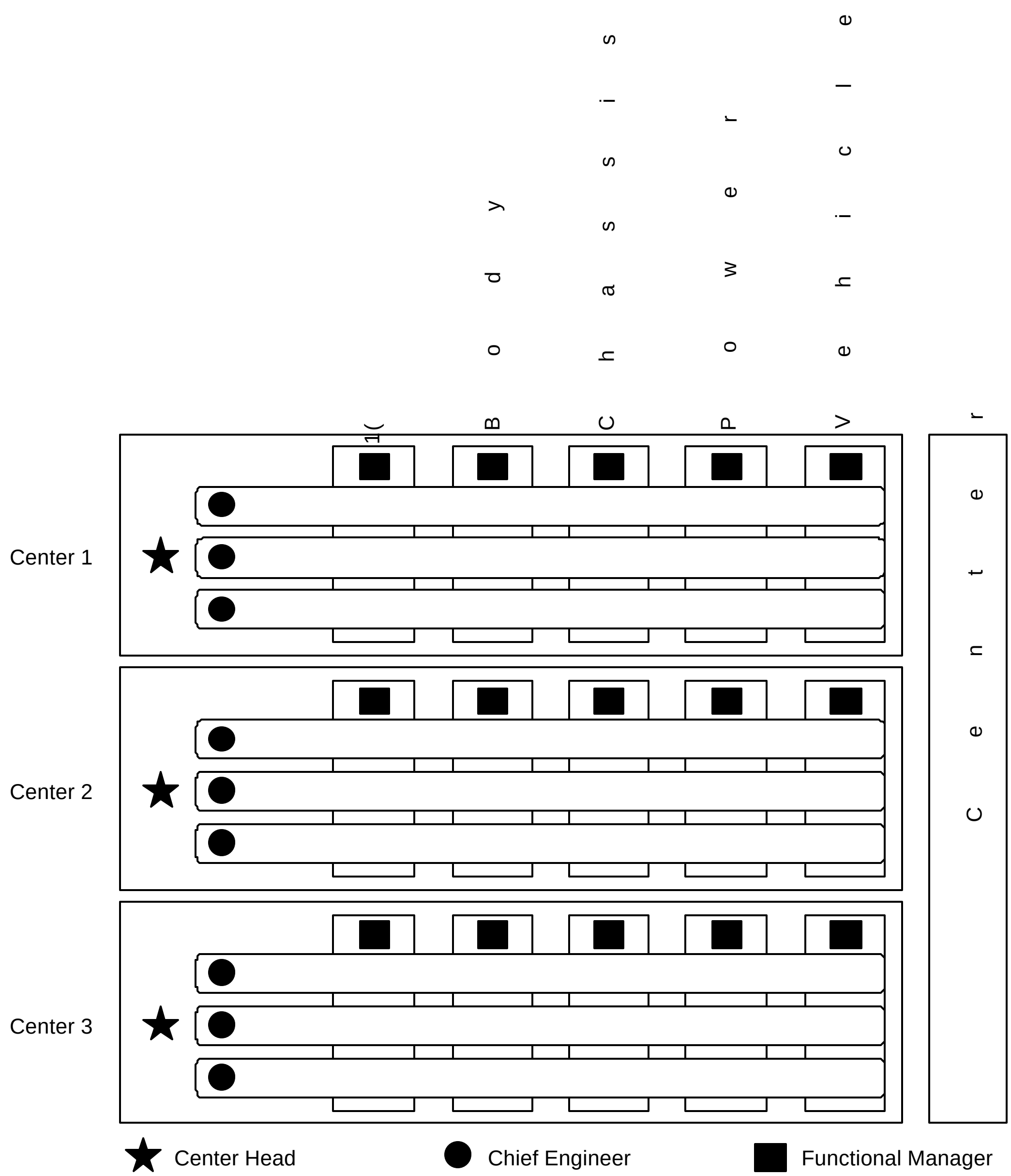

Figure 5 – Toyota's Development Center Organizational Structure

Development centers may actually embody more of a product structure rather than a matrix structure, however, because the heads of each center have authority over all the projects within their respective center as well as the responsibility of supervising all of the functional divisions in its center. In other words, the projects and the functional divisions report to the same manager.

As can be seen in the figure, within a given development center, there are both functional divisions and projects. Cusumano and Nobeoka report that each development center works on approximately five projects simultaneously and that Toyota reduced the number of functional divisions from 16 to six. Accordingly, the chief engineer of a product line has fewer departments and divisions to coordinate, and functional managers have fewer projects to staff and oversee. Essentially, Toyota has created small organizations (i.e., development centers) around different types of product platforms, which allows it to maximize component sharing and reuse. Also, reducing the number of functional divisions meant that each division had a wider range of responsibilities, which kept the personnel from becoming too focused in their respective functional area. In addition to the three primary vehicle centers, Toyota added a fourth development center that focused on developing new technologies and common components for the three primary centers. In a sense, this reduced the amount of work that each development center had to do by assigning certain development items to the component and system development center (Center 4). Toyota defined guidelines to determine whether a component was to be developed by a project within a primary center or by Center 4. In reducing the number of functional divisions during the reorganization, those that were not merged with another division, and that developed common components (i.e., audio systems), were absorbed by Center 4.

The objectives of Toyota's reorganization were to enforce multi-project management and component sharing, and simplify project management. Each development center has its own functional divisions; therefore, there are redundancies in engineering. While most organizations do not find these types of recurrences beneficial, Toyota is large and profitable enough to tolerate them in order to achieve its noted objectives. Cusumano and Nobeoka concluded from their study of the automotive industry [1] that there is a correlation between the type of structure utilized and the size of the organization. Typically, they found that larger organizations (i.e., Toyota and Ford) use development centers, while smaller organizations with production levels under two million (i.e., Mitsubishi and Mercedes) use matrix structures. They noted exceptions for large organizations, however. General Motors, for example, uses a "semi-center" structure and Chrysler uses a product structure. A semi-center structure is a mix between the center and functional structures. Cusumano and Nobeoka also spoke of additional factors that can influence the type of organizational structure used, such as imitation (organization ABC implements a development center structure because organization XYZ does) and the number of different products developed.

In summary, an organization's structure should support its strategies, objectives, capabilities, size, and industry, in addition to other factors that might influence its business. Organizational structures should simplify project management, communication, and coordination of tasks. It is not sufficient for an organization to simply maintain a structure – it should also be well-communicated to the personnel. Clear communication of the structural strategy can instill the "big picture" that many personnel lack. Roles, responsibilities, accountabilities, and communication interfaces are inherent in an organizational structure. If organizations want to use their structure to support their business strategy, then it must be communicated to the people embodied by the structure.

2.4.1.3 Project Types and Project Strategies

The nature of an industry or market can affect the type of projects that an organization executes. There are several different types of projects in which an organization could engage: new product development for a unique customer, new platform development for a product line, derivative product development for a product line, and research and development. New product development for a unique customer typically requires a large budget, and limits reuse. New platform development for a product line also requires a significant budget, though, on the contrary, augments reuse. Platform development projects are in direct alignment with product line engineering; for this reason, it would be expected that an organization implementing PLE would utilize this project type. The first type of project might also be utilized by a PLE organization but to a lesser extent. Derivative product development projects are concurrent or subsequent to platform development, and, hence, also support a product line engineering strategy. Research and development (R&D) projects usually support the other types of projects by feeding new technologies into them, and consequently keep products competitive.

In addition to project types, organizations can also use project strategies to reinforce PLE. Cusumano and Nobeoka [1] suggest that there are four types of project strategies that allow an organization to take advantage of platform architectures or component sharing: new design, concurrent technology transfer, sequential technology transfer, and design modification. A depiction of these strategies can be found in Figure 6 (Cusumano and Nobeoka p. 10).

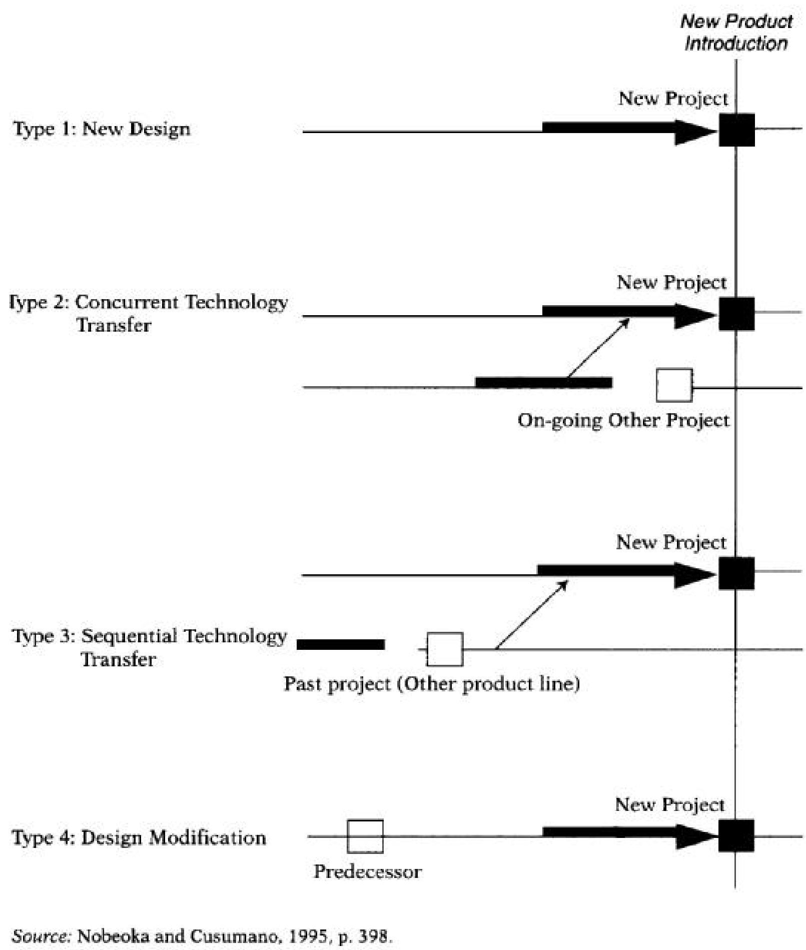

Figure 6 – Project Strategies [1]

A *new design* project strategy incorporates the latest technologies in a “clean sheet” design. The new design could be a platform architecture for a planned product line; however, Cusumano and Nobeoka do not specifically mention this approach. The next strategy, *concurrent technology transfer*, requires extensive planning and coordination in order to share a platform prior to completion of the first product (refer back to figure). It is the parallel development that allows the product teams to share tasks and optimize the platform for both projects before the design is finalized, thus, preventing costly design changes later, and the creation of two platforms instead of one. Cusumano and Nobeoka’s studies have shown that a concurrent technology transfer strategy can require fewer engineering hours than the other strategies discussed [1].

Sequential technology transfer, the third type of strategy, allows a new project to inherit an already-designed platform from another product line. Since the platform design is completed in this case, the project inheriting the platform could be more constrained in terms of design compared to a project that utilizes a platform concurrently with another project. If changes were absolutely necessary, then it would require some amount of rework. There is also the chance that the previously designed platform has “old” technology. Typically, if an organization is using outdated technology in a new product then they are not going to be competitive in the market. Another problem that could occur with this strategy, as well as with the following design modification strategy, is that the product team inheriting the “older” platform is not likely to be the same team that developed the inherited platform. It can be difficult attempting to reuse a platform in a new product without any of the original developers on the team, and based only on specifications and drawings [1].

The last strategy, *design modification*, is similar to *sequential technology transfer* in that a previously developed platform is reused. Conversely, with this strategy, the platform comes from the same product line. This strategy could be used if an organization wants to replace an obsolete product with a newer version. The design modification could occur as long as seven years after the introduction of the original product [1]. Cusumano and Nobeoka’s studies have shown that sequential technology transfer and design modification can potentially require more engineering hours than a new design.

Cusumano and Nobeoka's studies have shown that automotive companies that utilize the *concurrent technology transfer* project strategy perform better than those that maintain one of the other three strategies. Specifically, automakers that implemented concurrent technology transfer grew between 37 and 68 percent more over three years compared to companies that followed one of the other strategies. The sequential technology transfer and design modification strategies could imply that the product development organization did not plan to reuse the platform. Product lines should be methodically planned – including the timing of the market introduction for each product and the resource and technology sharing. A complete discussion of these strategies can be found in Cusumano and Nobeoka's book *Thinking Beyond Lean*.

2.4.1.4 Resource and Technology Sharing

Organizations may implement resource and technology sharing to reduce costs associated with product development as well as development time. If the resources or technologies are not shared by two or more development projects that are simultaneously ongoing, but instead any number of new development projects use the resources or technologies from a completed project, then this strategy might instead be called "reuse". For the purpose of this thesis, resource and technology sharing and reuse will be used interchangeably. People, work breakdown structures, and test equipment are examples of shared resources, while some examples of shared technology are platforms, components, or methodologies. Business goals, strategies, and organizational structures directly impact resource and technology sharing; therefore, these enabling capabilities must be refined to enforce resource and technology sharing in order to achieve the benefits. Communication and coordination of tasks also enable resource and technology sharing.

When an organization has defined product line engineering as a business strategy, then there is vast potential to reduce product development costs through resource and technology sharing. Some sharing can be more easily achieved if certain reinforcing characteristics are established. For example, the organizational structure that a company implements can promote resource and technology sharing. The development centers utilized by Toyota [1] enable management to plan for several products within a center to share components. This can be primarily attributed to the fact that comparable types of products that use similar technologies are organized into one center and, hence, can more readily share resources and technologies.

2.4.1.5 Incentives

The incentive strategy of an organization should reflect the business and development strategies. Just because an organization wants to achieve certain goals does not mean that the goals will automatically be achieved. There must be incentives for the personnel to work toward achieving defined goals and they must be aligned with the type of performance or outcome that is desired.

At Toyota [1], the head of each development center sets specific objectives for its respective center as well as objectives for each individual project within its center. The objectives are structured to enforce multi-project management with improvement in cycle time and cost. Cusumano and Nobeoka write in their book *Thinking Beyond Lean*:

> “Specifically, each center has incentives to increase component sharing among multiple vehicle projects, which is one of the best ways to reduce product costs. Project-centered management and “one-at-a-time” thinking cannot do this.” (p. 46)

In other words, Toyota offers incentives for the performance it wants to enforce. Typically, people will perform based on the metrics by which they are measured and the performance for which they are rewarded. If Toyota wants the development centers to utilize component sharing, then it is critical for it to recognize and reward those who engage in component sharing. Otherwise, without incentives, a project manager will not go out its way to coordinate with other project managers. Instead, a project manager will focus on its product and not consider the bigger picture.

2.4.1.6 Processes

Maintaining a process is one way an organization can improve itself (i.e., reduce costs and increase profits). When there are documented procedures that detail how product development should be executed, then it is less likely that redundancies will occur and important activities will be left undone. An organization needs to use documented processes to navigate its product line engineering practice. There are various types of processes that have different objectives, such as portfolio management, product development, and change control processes. A portfolio management process can provide a method for evaluating an organization's current product offering and determining what products to develop, while a product development process can guide an organization through the generation of a product. A change control process simply manages proposed changes to a product. Each of these processes can drive PLE attempts, however, they are not specific to product line engineering.

2.4.2 Political Perspective

2.4.2.1 Stakeholders

In order to give proper consideration, it is critical to identify who has a stake in the success of a business strategy or product development effort. It is also important to understand how the stakeholders impact a strategy or product development approach. Typical stakeholders of organizations developing products include:

- The organization itself (i.e., management and all other personnel)
- Vendors or suppliers
- Customers who may use an organization's product as a component within their product
- End users
- Regulatory agencies
- Shareholders

Product line engineering organizations will have such stakeholders, and it is interesting to contemplate the effects a stakeholder might have on a product – how a stakeholder might facilitate, jeopardize, or even benefit from PLE. For example, customers procuring a PLE organization's product can potentially achieve shorter lead times and cost savings relative to an organization that is not implementing PLE. Product line engineering can actually be used as a negotiating tool with some stakeholders.

2.4.2.2 Management

Any improvement initiative or technology transition requires the support of senior management; product line engineering is no exception. Early involvement by senior management will make the transition smoother and timelier. There are decisions that need to be made that will impact the organization's success as well as individuals' careers. It requires "strong, solutions-oriented managers" (p. 40) to lead an organization through the early phases of a technology transition [3].

CelsiusTech [3] found that management played a key role in its paradigm shift to product line engineering. The following excerpt was taken from Brownsword and Clements' case study on CelsiusTech:

> "Managers in the formative years of the product line required strong knowledge of the product line concepts, the technical concepts to be applied, and the business rationale for the product line approach. In addition, they needed strong planning, communication, and innovative problem-solving skills." (p. 40)

The CelsiusTech management team had to deal with personnel who resisted the transition; a substantial effort, therefore, was made to communicate the rationale behind its new business strategy. During the transition, CelsiusTech lost some personnel (i.e., they left the company) that could not comprehend the product line approach. Whatever strategy an organization chooses to maintain, it is critical that it be thoroughly and repeatedly communicated to the personnel.

Not all organizations have made the revelation that CelsiusTech has made. In general, management needs to stop thinking of products as individual development efforts. It needs to transcend the idea that each project exists in isolation and organize projects to take advantage of people and technology. Instead of working towards one hit product, the organization needs to be working at delivering a "stream of new products" [1]. Cusumano and Nobeoka's studies have shown that "aiming for hit products in isolated projects is not enough". They go on to say that "the best companies today view projects as part of a portfolio and make the most of their investments by introducing new technologies in as many products as possible as frequently as possible" (p. 7). Product line engineering supports this strategy. Cusumano and Nobeoka refer to this style as "multi-project management" [1].

2.4.2.3 Responsibility/Accountability

Responsibilities should be clearly established within organizations in order to ensure that the necessary tasks are performed. Sometimes it might not be clear who is responsible for certain deliverables – or who is accountable for the success or failure of a business strategy or product development effort. A PLE strategy suggests that someone needs to be responsible for keeping the platform and the derivative products aligned. In other words, each derivative project should not change the platform to meet its particular needs. Instead, the platform should be consistent in each derivative product. Maintaining alignment can be involved, and, therefore, it requires the organization to define that responsibility.

2.4.3 Cultural Perspective

2.4.3.1 Communication

Product line development requires collaboration between marketing, engineering, and manufacturing within an organization. Additionally, there needs to be clear lines of communication between the product line engineering organization, its suppliers, and its customers. Henceforth, during the transition to product line engineering, and once it has been established, effective coordination of activities and communication among the mentioned groups are critical. Communication occurs in a myriad of ways. For example, verbal communication can transpire in the form of meetings, telephone conversations, or presentations; while textual communication can be conveyed through reports, e-mail, or fax.

2.4.3.2 Resource and Technology Sharing

Resource and technology sharing, characteristics that reinforce product line engineering, can be cultural concerns in addition to political ones. If an organization's culture is not driven to multi-task, share information, or document lessons learned, then these tasks will be performed minimally. Product line engineering can be further enhanced if an organization's culture is inclined to share resources and technologies across projects.

2.4.3.3 Training

When an organization makes a technology transition, the technical processes of the business are not the only items that need to change, the people need to change, too. One way to facilitate a culture change is to provide training. It is crucial for an organization to educate its personnel as well as its customers and suppliers on the new business strategies, technical methodologies, and processes. When shifting an entire organization to a new paradigm, one of the objectives should be to minimize the impact of the change on the organization's productivity; therefore, change needs to be managed.

CelsiusTech [3] realized the risk involved with making a technology transition and used training to mitigate the identified risk associated with the change. The CelsiusTech management team played a significant role in its transition to product line engineering. CelsiusTech relied on flexible and motivated managers to lead the rest of the organization, providing on-the-job mentoring from external consultants for the managers. In addition, some of the lower-level managers went through the technical training provided for the technical staff so that they could better understand the new technologies and development approaches that would be fundamental to the new product line engineering strategy. CelsiusTech also believed that it was important for managers to understand the technical difficulty associated with the transition, and that attending the technical training was one way of communicating, to managers, the intricacy involved.

CelsiusTech's original approach to training the technical staff was not successful, however. The training curriculum initially consisted of about eleven days, which included instruction on the software methodology, language, and development environment. While this curriculum did teach the concepts, CelsiusTech found that it was not sufficient to prepare the technical staff to implement the new methodology and language in practice. The revised training approach, which was developed by external consultants, included eight weeks of classroom education followed by on-the-job mentoring. CelsiusTech found that while the revised curriculum did an adequate job teaching theory as well as practice, on-the-job mentoring was critical as well. Although the external consultants initially performed the training, a core group of CelsiusTech developers was qualified as instructors and continued the training and mentoring program. According to the case study, over 125 software developers were trained between 1987 and 1989. It was not as easy as just educating the current personnel;

however, the training program was a continuous effort at CelsiusTech as a result of personnel turnover.

It was necessary to “refine and tailor” the training curriculum as the product line engineering methods, processes, and tools evolved at CelsiusTech. Training was a management priority and, therefore, the training program was well-planned and managed. Brownsword and Clements [3] reported that “as CelsiusTech staff members increased their ability to explain the product line approach internally, they became more effective in conveying their message to their customers” (p. 64). They also reported that a users group formed between the product line customers and CelsiusTech, which was beneficial to both parties. For the customers, “the users group offered a manner by which they could procure systems at a lower cost than they could individually.” While for CelsiusTech, “the users group allowed them to maintain a tightly controlled product line capability, since their customers were essentially procuring systems as a group rather than individually” (p. 65). CelsiusTech also trained some of its suppliers.

CelsiusTech used its training strategy to mitigate the risk involved with making a transition to product line engineering. In addition to communicating the new business strategies and teaching the new development methodologies, the training program ensured the use of a common development process. From this example, it can be derived that a well-planned and substantial training program is necessary in order for organizations to make significant changes to their business strategies.

2.4.4 Remaining Questions

After researching past experiences and literature on the topic of product line engineering with respect to organizational characteristics, there are questions that surface. The following questions were the starting point for the research methodology used to achieve the main objective of this thesis:

Strategic perspective

- What metrics are being used to monitor platform and product line performance?
- What type of organizational structure best facilitates product line engineering so that the potential benefits associated with this approach may be achieved?

- What types of organizational processes are required to implement product line engineering?

Political perspective

- How do stakeholders impact or facilitate an organization's product line engineering efforts?
- What role does senior management need to play in a product line engineering organization?
- Who is responsible for maintaining alignment among the platform and the derivative products?

Cultural perspective

- How does organizational communication facilitate product line engineering?
- What types of training do product line engineering organizations utilize?

3.0 Research Objective and Methodology

The main objective of this thesis was to identify non-technical, organizational characteristics that attribute to successful product line engineering. In order to answer the questions that emerged from the Section 2.0 literature review, and, thus, identify organizational characteristics that attribute to product line engineering success, it was necessary to observe organizations that are currently implementing PLE. Because this research was an exploration of organizations implementing PLE, it was concluded that case studies derived through a series of interviews would be more insightful than using a standardized survey. Additionally, it would be difficult to collect a dataset from the aerospace industry large enough to warrant a statistical study – and observing organizations from other industries as well as the aerospace industry suggests, in order to gather qualitative data, a case study methodology. At this point, the preliminary list of questions stated in Section 2.0 was expanded to the detailed list of interview questions found in the Appendix. The series of questions in the Appendix were documented prior to the interviews in order to systematically gather the same data from each individual. The questions were structured around the defined strategic, political, and cultural perspectives and were reviewed by several people in an attempt to remove bias.

The next step was to select the organizations to study as part of this thesis. Not all of the four organizations selected were operating in the aerospace industry (see Table 1). The decision to benchmark other industries was made in order to observe what they are doing to employ product line engineering, and then leverage the attributes in the aerospace industry.

Table 1 – Industry and Number of People Interviewed per Organization

Organization	Industry	Number of People Interviewed
A	Aerospace	2
B	Office Automation	5
C	Aerospace	3
D	Automotive/aerospace	4

The organizations were selected for exploratory interviews based on their known product line development efforts. In addition, it is evident as to why Organizations A and C were chosen; they are both representatives of the aerospace industry. On the other hand, Organization B was selected because it, like a typical aerospace organization, creates complex products, and, unlike most aerospace organizations, creates commercial products. For at least these reasons, Organization B was a desirable organization to study. Furthermore, since Organization D serves both the automotive and the aerospace industries, it had multiple perspectives to offer, which was also desirable. There was no attempt a priori to assess the level of success with which the organizations were implementing product line development.

The individuals within each organization were selected for interviews based on their involvement with the product line development. A total of fourteen people were interviewed – the breakdown of people interviewed per organization was shown in Table 1. More than one person from each organization was interviewed to improve reliability of the information as well as increase the overall amount of information about a particular organization. Generally, the first interview with someone from an organization included questions on the strategic, political, and cultural perspectives. Additional interviews within the same organization focused first on the political and cultural perspectives, and then on the strategic perspective if time permitted.

The first round of interviews was conducted via telephone during the fall of 1999 and each interview was at least one hour in length. In most cases, an individual was contacted for a second and third interview in order to clarify and increase the depth of information about the respective organization. Either a telephone call or e-mail was used to perform the follow-up interviews. All of the data gathered on an organization was used to formulate its respective case study. Finished case studies were sent back to the respective organizations and a representative (i.e., someone that was interviewed) from each organization provided feedback, corrections, and, hence, approved the case study for accuracy.

4.0 Case Study Data

4.1 Organization A

Organization A, which develops turbine power systems, was chosen to be a case study because it has established platform-based products and development processes. Organization A is a division of a larger technology-based corporation and has three primary strategic business enterprises (SBEs) within the organization that focus on different markets. Overall, the turbine power systems business employs approximately 5500 people; 1475 are in engineering and development. The following case study data was obtained through numerous interviews with two people from the turbine power systems organization.

Organization A has historically developed product lines within an industry where technology evolves slowly. The primary reason that they have implemented product line engineering is because the industry, which is now relatively mature, has dictated this type of product development strategy. Model commonality and customer focus drive product development – and it is more cost effective to operate from a family of models rather than individually developed models where each could potentially end up different. Organization A's product lines are profitable and they have had admirable success with the market. The most successful SBE has 75% of its market share and is ranked number one against the competition. The other two SBEs are profitable as well, maintaining 30% and 22% of their respective markets.

4.1.1 Strategic Perspective

4.1.1.1 Goals and Metrics

Organization A has a clearly defined strategic goal associated with the development of its turbine power system product lines – to manage the configuration of products and align with customer requirements. A "strategic plan" (STRAP) for achieving its business objectives is documented in detail each year. There are monthly and quarterly technical reviews of each product line as well as monthly and quarterly business priority reviews where cost, delivery (milestones), quality, and productivity are assessed.

There are no specific metrics gathered by Organization A to measure the performance of its product line engineering effort. However, the formal metrics previously mentioned (i.e., cost, delivery, quality, and productivity) are indicators of product development performance in general. Organization A utilizes a six-phase product development process to take a product from concept to launch. Several additional "lower-order" metrics by which the products within a product line are measured come from this process:

- Cost per operation (i.e., per drawing, per analysis, per test)
- Process/product cycle time
- Rework (i.e., amount and cost of rework, time to do rework)

In addition, the organization uses the following types of metrics to monitor the progress of its programs. These metrics are typically assessed during the product development process phase gate reviews:

- Actual versus planned budget
- Actual versus planned schedule
- Risk items (including mitigation and status plans)

The following "figures of merit" are examples of metrics used to evaluate and ensure that design intent is being met technically:

- Functional efficiency (i.e., fuel consumption)
- Weight
- Time between failures (field data)

A metric that clearly shows one of the benefits of product line development is the time it takes to develop a derivative product from the platform product. It takes Organization A approximately 20%-30% of the time to develop the platform to spawn a derivative product. So where it takes three to four years to develop a new platform product, it could take anywhere from approximately seven to 14 months to generate a derivative. In addition, derivative products require fewer resources and thus only expend 20% of the platform cost ($20 million versus $100 million).

4.1.1.2 Organizational Structure

Organization A's SBEs are product aligned – each SBE generates a similar yet distinct type of product that corresponds to a particular market. The organizational structure depicted in Figure 7 is similar to Toyota's "center" organization that was described in Section 2.4.1.2. [3] The entire organization is structured to support the development of product lines – a hybrid of the product and matrix structures. Program personnel (i.e., people assigned to specific programs) report to both product line directors and functional directors, and their performance is reviewed by both directors as well.

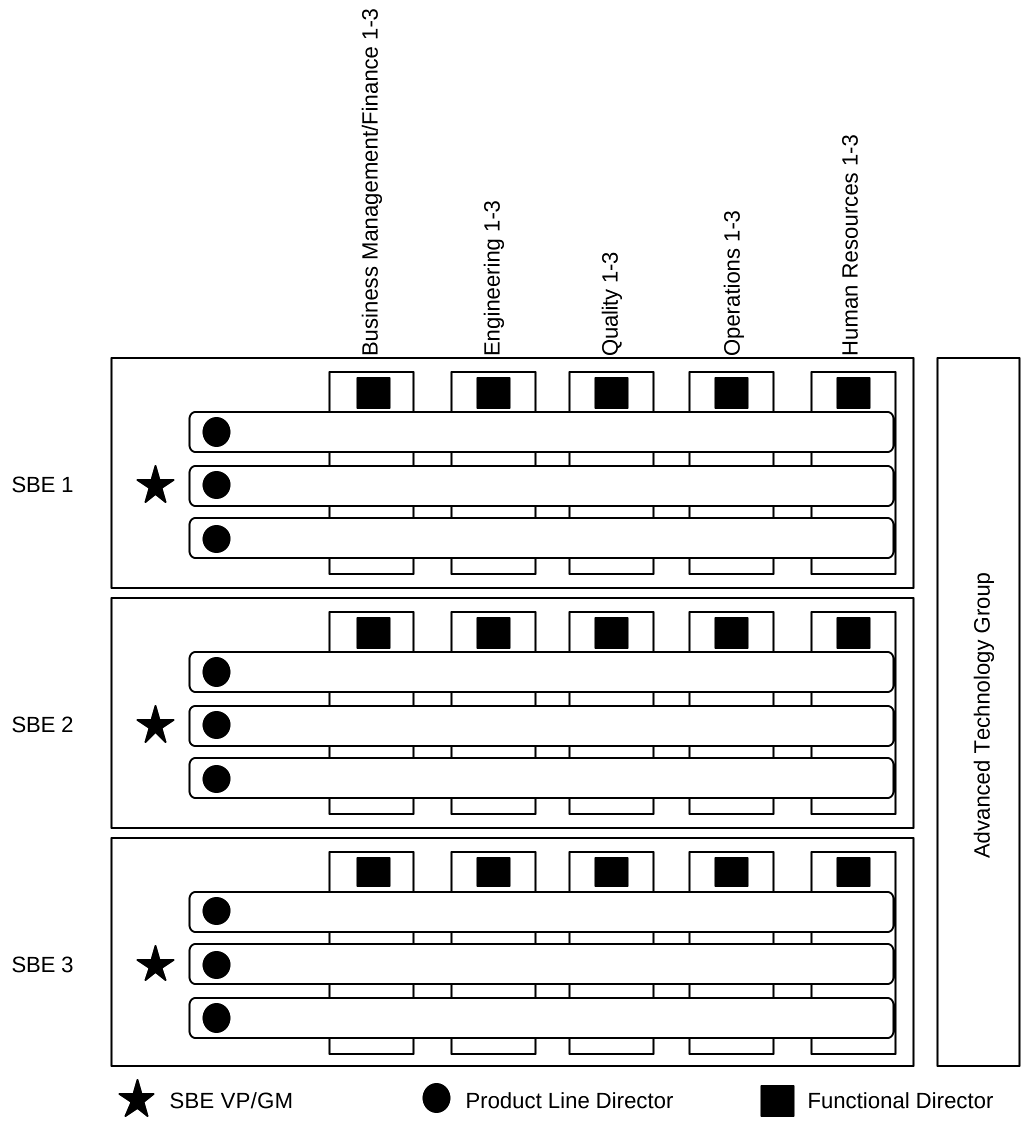

Figure 7 – Organization A's "Center" Organizational Structure

Although resources are "owned" by functional directors, the product line directors are said to have almost equal power in comparison to the functional directors – a so-called

[3] The figure may not represent the exact number of functional groups, products, product lines, etc.

“49/51 split”. Yet, there is no apparent “power struggle” between the directors. Not pictured in Figure 7, the functional directors are accountable to functional vice presidents that report to the president of Organization A. The vice president and general managers (i.e., VP/GMs) of the SBEs also report to the president of the organization.

4.1.1.3 Projects Types and Project Strategies

Organization A develops several different types of turbine power systems – each SBE addresses a distinct market. The products are somewhat modular and, hence, support component sharing and component swapping. The organization can also scale components or fabricate-to-fit its products (refer back to Figure 1 for a pictorial depiction of these types of modularity). Currently, Organization A has 14 product lines existing simultaneously, which accounts for the widest product range of any such company in the world. Comparable to competitors, it takes approximately three to four years to develop a new design platform and it is used for approximately 30 plus years. Five to ten total derivative products are typically developed from one platform – and derivative products are developed at a rate close to one derivative per product line per year. This rate is also comparable to competitor rates, however, for a single company, Organization A still has the most products to offer.

Organization A works on each of the four project types described in Section 2.4.1.3 – new product development for a unique customer, new platform development for a product line, derivative product development for a product line, and research and development. However, *new product development for unique customer* and *new platform development for a product line* are basically “one in the same”. Organization A typically develops a “launch product” (i.e., platform product) for a “launch customer” (i.e., unique customer). The launch customer helps fund the new product development and define the preliminary requirements. Although the launch product is developed for a unique customer, Organization A gets synergy from the investment to create new products for other customers. Derivative products are planned along with the launch product and marketed to multiple customers. Thus, new product development for a unique customer and new platform development for a product line are essentially the same for Organization A, and will be referred to as new platform product development in this section.

There are approximately five new platform product development projects and ten to twelve derivative projects progressing simultaneously at Organization A. In addition, there are 50 to 75 R&D programs simultaneously ongoing in the Advanced Technology Group. Although there are many more R&D programs compared to new platform product development and derivative projects, each R&D program has a smaller scope and thus consumes fewer resources than the other types. In turn, derivative projects have a smaller scope and require fewer resources than the new platform product development projects. Approximately 90% of the R&D programs are small technology projects that could potentially feed into larger demonstrator projects. These “incubator technologies” are quickly evaluated for feasibility and either further pursued or cancelled. The other 10% of the R&D programs are demonstrator programs. A typical R&D budget is 2.5-3% of sales and is sometimes government funded. A summary of the project types is found in Table 2.

Table 2 – Organization A’s Project Types

Project Type	Number of Projects (estimated)
New product development for unique customer	5
New platform development for product line	Included above
Derivative product development for product line	10-12
Research and development	50-75

Figure 8 shows that Organization A uses all four of the project strategies identified earlier in Section 2.4.1.3. The largest percentage of projects is categorized as concurrent technology transfer (50%), followed by sequential technology transfer (25%) and design modification (22%), and lastly new design (3%). The new design projects are extremely large and costly, which is why they account for the smallest percentage of projects.

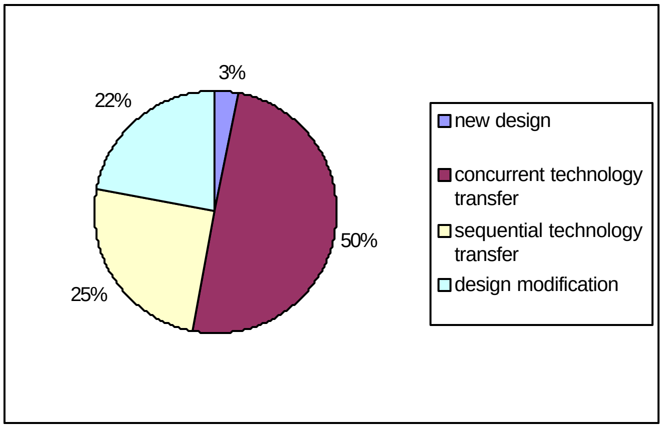

Figure 8 – Organization A's Project Strategy Utilization

Even though they are few in number, together the new design projects require approximately 65% of Organization A's development budget. Likewise, concurrent technology transfer projects necessitate 20% of the overall development budget, while sequential technology transfer and design modification projects only need 10% and 5% of the budget, respectively. An example of sequential technology transfer at Organization A is when they take a turbine power system designed as a military product and adapt it into a commercial product.

4.1.1.4 Resource and Technology Sharing

There is not a defined goal to achieve a set percentage of technology sharing, although it happens quite readily and can be better quantified than the amount of resource sharing. Roughly 10% of the development projects share "exact" (no modification) components, 30% share "scaled" components, and 50% share component technology. The modular product architectures facilitate technology sharing within an SBE as well as across SBEs. The organization also shares some standard design requirements by programming them right into the computer aided development tools that they utilize (i.e., Catia).

Because Organization A shares functional resources across product lines, management believes that this promotes technology sharing. However, there is not a formal process identified to strategically transfer people from program to program to enforce technology sharing. According to one manager, they can always do better. He says, "There is a lot of knowledge tied up in people rather than documented processes and, therefore, we lose knowledge when we lose people." Organization A does use a lessons learned database to capture and share knowledge across product lines and notices that the database is getting more use as younger engineers come into the organization. The organization also transfers people from one SBE to another, which propagates lessons learned and technological knowledge.

4.1.1.5 Incentives

The incentive structure was not specifically described as reflecting the organizational goals and structure. Incentives are tied to the cash, delivery, quality, and productivity metrics for a product line at the director level and above. The tasks required to meet these objectives are filtered down to individuals, however, the incentives are not. In order to ensure the short-term success of completing the platform product or a single derivative product, a project's yearly goals are reviewed quarterly. In addition, the product development process "phase gate reviews" also ensure that the project is heading in the right direction. The longer-term goals are captured in the STRAP, which is reviewed yearly. It is felt that sometimes visibility in the market is too limited to plan too far ahead. To have their people envision the "big picture" (working toward long-term goals) is an effort, as they are focused on delivering their particular product. The yearly STRAP review is the only way to instill the big picture focus within Organization A.

4.1.1.6 Processes

There is one product development process at Organization A, which is comprised of six phases that guide a product from concept to launch. The common engineering processes that stem from the product development process are used across all product lines and largely attribute to the organization's success. One manager thinks that problems are created when people don't follow the discipline of the process and instead take short cuts. Portfolio management was identified as an area of weakness, including the process of deciding whether or not to pursue a new project.

4.1.2 Political Perspective

4.1.2.1 Stakeholders

The business enterprises are stakeholders in Organization A's product development, including management, engineering, quality, finance, and manufacturing.

In addition, the entire supply chain could be considered a stakeholder. Each stakeholder has an interest in the success of Organization A's product lines.

External (hardware) suppliers are critical to Organization A's business and have a stake in the ultimate product that is produced. Organization A purchases approximately 70% of the parts that go into their products and therefore make about one third or less of the parts in-house. Over the years, the relationship between Organization A and its suppliers has grown; they have gone from calling them "*vendors* to *suppliers* to *partners*". Sometimes the suppliers or "partners" are even trained in Organization A's processes.

Some of these partners do more than supply parts; they supply financial support for the product as well. Because of the large investment associated with launching a new product, Organization A finds "risk sharing partners" (RSPs) to help fund the development in return for a percentage of the sales revenues. The RSPs are not always hardware suppliers. Some RSPs might provide services or resources in exchange for a "piece of the pie" – but no matter what they offer (i.e., hardware or services), they all bring "money to the table". Not all of the suppliers are RSPs. Organization A might acquire hardware from a supplier without that supplier investing money in the development to become an RSP.

4.1.2.2 Management

At Organization A, senior management defines product line development. They make the high-level decisions and pass them down to the rest of the organization, holding the product lines accountable to meet their defined goals. Senior management plays a significant role in determining which product lines to develop, and is also concerned with planning and supporting product lines. Overall, management is heavily involved in the organization's product line engineering effort since it is basically the manner in which they have historically done business.

Although senior management at Organization A ultimately decides whether or not to pursue the development of a product line, there are other stakeholders involved in the preliminary decision-making process. First of all, the customers and market drive product development and therefore have the biggest influence on new projects. Marketing is the primary interface with the customer and consequently plays a role, to some extent, in product development decisions. They work with management to decide which projects to pursue. Engineering gets involved when management needs opinions about the technology and resources required. The directors and VP/GMs typically make final decisions, however. The investment for Organization A's most recent product line venture was so significant ($250 million) – a major strategic business decision – that they went to the Chief Executive Officer (CEO) of the overarching organization for approval.

In planning a product line, senior management must work with the product line directors, design and test engineers, and manufacturing. Along with the business plans, they must determine if the current test facilities are adequate and plan for new tooling or machinery if necessary. The planning is simply not left up to senior management – engineering (as well as the other disciplines mentioned) is heavily involved, too.

In respect to senior management "support", there are different levels for various product lines. The level of support depends on the program size, the importance and visibility of it, and also program performance. Organization A has a myriad of programs that run day in and day out; it would not be practical for senior management to visibly show support for all of them. On new and very large product development programs, senior management shows consistent support by attending meetings, talking about the program at trade shows, getting involved when there are major challenges with suppliers or customers, and, most importantly, by providing the necessary resources. "Of course," exclaimed one manager, "if you screw up enough, you'll get more help than you want!" There are weekly meetings at the vice president level that typically highlight the top five poor performance programs. Also, if it becomes apparent that a program is getting into trouble, the president or another senior manager will ask to be briefed in order to determine what they can do to help. It is clear that there is top down interest in the development of product lines at Organization A.

4.1.2.3 Responsibility and Accountability

The product line directors are accountable for the profit or loss associated with their product lines. Phase gate reviews and quarterly reviews are used to ensure that the product lines are on track. These reviews, as well as yearly STRAP reviews, are necessary to monitor whether or not derivative products are deviating from the product line strategy. The product line director must safeguard that derivative product teams do not make changes that would impact the platform or the entire product line. There is no explicit process to prevent derivatives from deviating, but "close communication" is maintained between the platform or "parent" team and the derivative teams in order to keep everyone informed of potential changes. One manager interviewed said, "It would be a mistake to isolate a derivative product team – the derivative team should be co-located with the parent team." The product line director is responsible for all aspects of the product line and is accountable to the SBE VP/GM. Overall, the SBEs are businesses with total profit and loss responsibility.

4.1.3 Cultural Perspective

4.1.3.1 Communication

Organization A management believes that it is critical to have efficient communication. Although execution is not perfect, most people are informed via informal meetings, e-mails, and regularly scheduled formal meetings and reviews. Information is communicated from the top down as well as from the bottom up.

The president of Organization A holds formal quarterly meetings with management to communicate downward the business priorities and financial information. In turn, management informally conveys this information to the rest of the organization, sometimes using e-mail to outline visions and strategies communicated from the top. Senior management feels that communication is so vital that in addition to the formal quarterly meetings, occasionally it holds "all-management" offsite meetings that include hundreds of managers. Meetings of this caliber are major time and money commitments, but they provide Organization A with a way to share information across the board and communicate questions and answers – to really "dig into business". Senior management's participation has improved over the years by becoming more visible to business and technical management. In addition to the formal communication meetings where information is transmitted, there are also weekly staff meetings that provide people with the opportunity to relay information back to the top. At Organization A, information regularly flows in both directions.

Co-locating product line teams is the best way to facilitate communication at Organization A. All 250-300 people on one of the newer platform programs physically sit in the same building on the same floor. One manager admits that co-location doesn't make communication automatic, but it does facilitate it. Monthly and quarterly formal program reviews, as well as informal meetings, are used to communicate status and direction. E-mail is also used among a product line team to communicate questions, answers, etc.

The product line directors primarily communicate information across product lines. Moreover, there is a core engineering management team that monitors all of the programs promoting best practices and lessons learned. Product line directors have to coordinate in order to meet their individual goals and, therefore, are fully networked together. A business priority matrix maps out the objectives they must achieve. Organization A has a lessons learned database for the projects to utilize. One manager believes that, typically, managers need to get into the habit of requesting their staff review the database for information.

4.1.3.2 Resource and Technology Sharing

Organization A has a resource allocation process that examines all program needs and the organization's resource capacity to meet those needs. They also prioritize the programs, first by customer demand and then by ability to create revenue. The top priority programs are allocated the necessary resources. However, sometimes it is a matter of the "squeaky wheel gets the grease".

There is a lot of competition for resources between product lines, and people generally take care of themselves first. Therefore, engineers tend to work on one product line at a time. Meanwhile, they could work on a variety of programs without ever leaving a specific product line. Organization A identified staffing continuity as a weakness and, consequently, there is no formal process for strategically sharing resources to promote technology sharing.

4.1.3.3 Training

Organization A does not have training exclusively for product line development. They have a significant amount of training courses that are specific to tools and functional skills. In addition, they train the organization in corporate methods and processes (i.e., total quality training, etc.).

4.2 Organization B

Organization B, which develops printing systems, was chosen to be a case study because of its known platform strategy. Organization B conducts business in a mature and highly competitive market where technology typically evolves over a short span of years. As a division of a larger printing systems corporation, Organization B, in a sense, represents one of three main product lines in the corporation. The overarching corporation's three product lines are based on different applications by end users – or different market segments. Within Organization B there are many products developed from platform components. The product lines to which these products belong address the needs of several different market segments. The organization employs about 2000 people; approximately 1400 are in engineering and development. Five people were interviewed from Organization B to gather data for this case study.

Organization B historically developed "point products", which were not strategically developed from platform components, and, consequently, there was little resource and technology sharing or reuse achieved. Furthermore, there was no "coherence"[4] between the point products, and the development efforts were inefficient. The primary reason for shifting to a platform strategy approximately four years ago was to stay competitive in the market place. By using a platform strategy to reduce time-to-market, development costs, and overall long-term sustaining costs (maintenance of products in the field), Organization B surmised it could be more competitive. It is still working on changing processes as well as the organizational culture, but it has already achieved some of the benefits associated with its platform strategy (i.e., increased reuse and coherence, and reductions in time-to-market, etc.). It is also working on removing/replacing the legacy point products from the field with platform-based products. This effort has substantial transition costs resulting from it. Nonetheless, Organization B is part of a six billion-dollar business where it is ranked number one against its competitors.

[4] Coherent products have consistent user interfaces, document output, operability, behavior, etc.

4.2.1 Strategic Perspective

4.2.1.1 Goals and Metrics

Organization B has a clearly defined strategic goal pertaining to the development of its platforms and product lines. Specifically, there are "coherency requirements" that all of its products must meet. The strategic plan, which spans three to five years, is reviewed continuously and updated yearly.

Product development programs are reviewed quarterly by Organization B's senior management. To ensure that a product meets the coherency requirements (or is "enterprise coherent"), program management also reviews the programs monthly. A product cannot pass through a "product development process phase gate" without being enterprise coherent. Thus, the coherency requirements are a means of measuring the performance of a platform or product. In a sense, compliance with the coherency requirements is a metric. In addition, some typical metrics assessed in programs reviews are:

- Actual versus planned budget
- Actual versus planned schedule

Some other metrics that Organization B tracks are:

- Slip rate (time it takes a product to go from definition to launch)
- Risk items and mitigation plans
- Software quality – errors per 1000 lines of code
- Hardware quality
- Performance (i.e., speed, reliability, image quality)
- Product features (i.e., functionality)
- Number of problem reports before/after launching product into the field

It took approximately 2.5 years to get the first platform into the field. At the time of the interviews, Organization B had delivered three platform-based products to the market. By using platform components, Organization B can now develop a product in about half the time it took to develop a point product ten years ago, and it is expected that this measure will improve. Its objective is to release a new product each year with maintenance releases every six months.

4.2.1.2 Organizational Structure

The structure of the overarching corporation, of which Organization B is a part, could be considered a "semi-center" type. Organization B is one of three "centers" within the corporation – and functional groups like marketing, sales, and customer documentation are managed at the corporate level rather than the center level (making the corporation structure a semi-center type rather than center type). Organization B's structure alone could be characterized as primarily functional. A depiction of this structure is shown in Figure 9.[5]

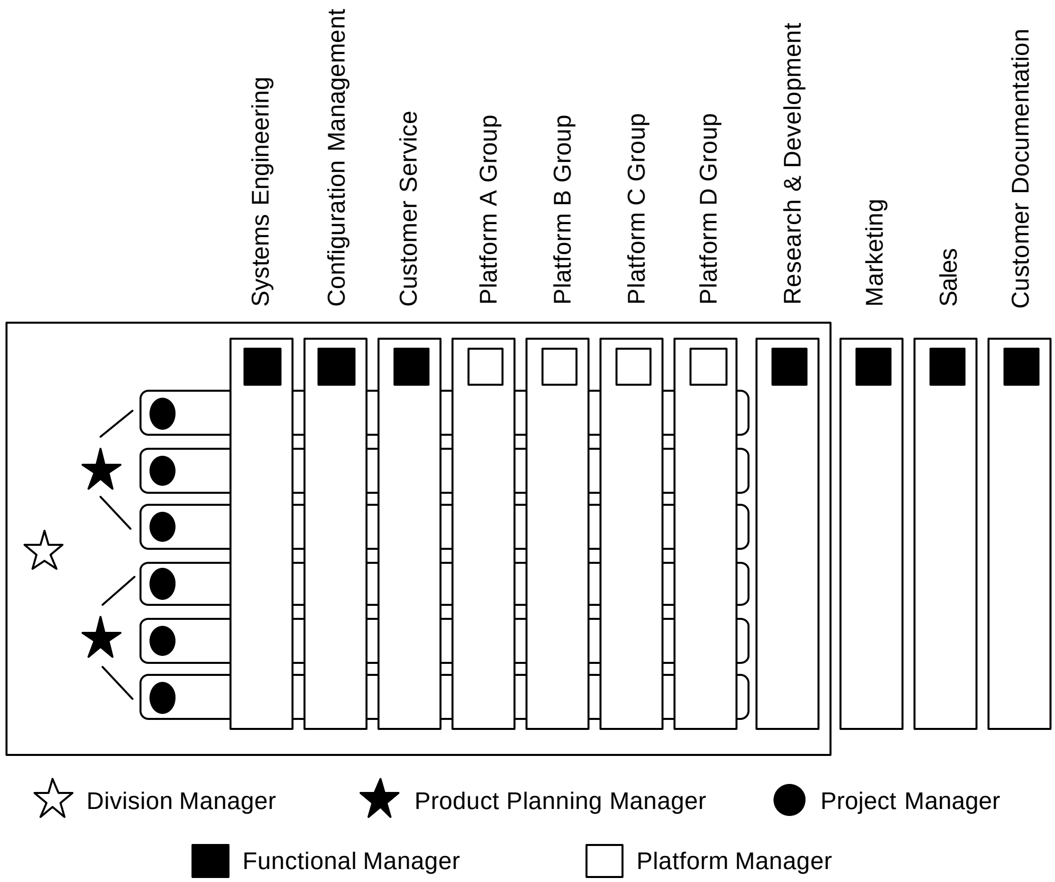

Figure 9 – Organization B's Functional Organizational Structure

Figure 9 shows the marketing, sales, and customer documentation functions outside of Organization B, since these functions are again managed at the corporate level. Organization B still utilizes these functions for its products and product lines, however. The functional managers and platform managers within Organization B report to a

[5] The figure may not represent the exact number of functional groups, products, product lines, etc.

central development manager (not shown in figure), who then reports to the division manager. The functional and platform managers "own" the resources and assign them to projects. This is the main reason that Organization B's structure is characterized as functional. The functional groups have to divide their time among the various projects and, hence, have responsibilities across product lines. Similarly, the platform groups support projects across product lines, where their main responsibilities are the development of their platforms. Project managers are responsible for the development of products from concept to launch, and utilize the platforms in their products. The project managers report to product planning managers who oversee the delivery of several products (i.e., a product line). The product planning managers are aligned by market sub-segments and report directly to the division manager, the head of Organization B.

4.2.1.3 Project Types and Project Strategies

Organization B develops printing systems for a particular market segment. Each system is composed of several hardware and software platforms. Combined in a variety of ways, the platform components develop different systems or products that meet the needs of several different end users. The products basically differ in functionality and performance. Accordingly, the system architectures can be characterized as modular – and exploit component-sharing and bus modularity as well as component-swapping and mix modularity. Figure 10 shows a generic example of this strategy. Although not depicted in the figure, there are interfaces between the platforms in a product.[6] One platform could go into any number of products. It typically takes two and a half years to develop a platform component, which could then be used for ten years. Instead of developing it internally, Organization B can elect to "outsource" the development of a platform to a third party, or, in other words, purchase it "off-the-shelf".

[6] Note that the figure does not completely represent a product per say, but rather, it graphically demonstrates the use of platforms in a product.

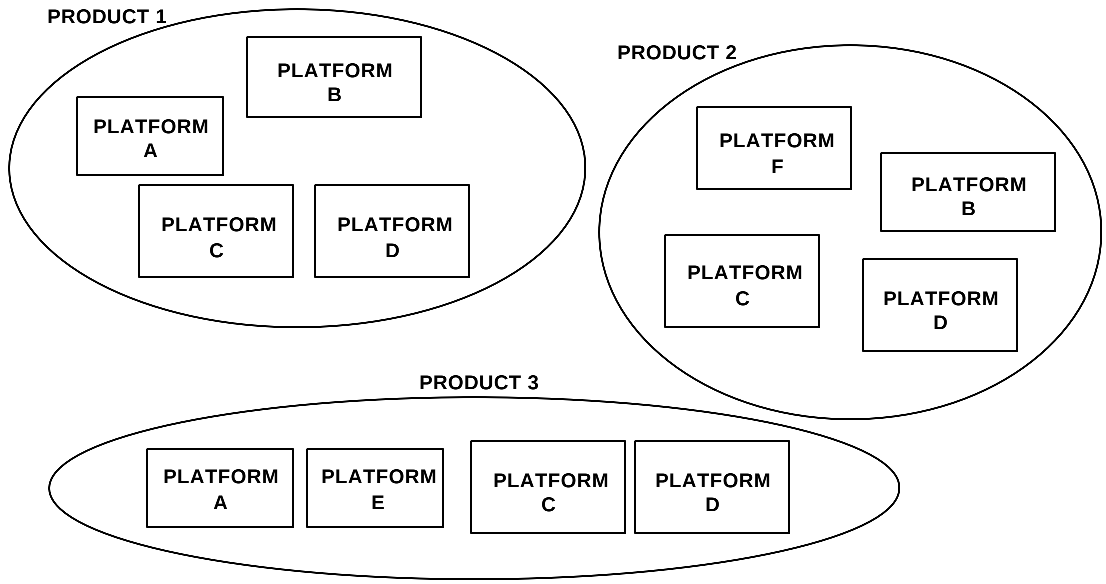

Figure 10 – Generic Example of Organization B's Platform-Based Products

Organization B does not create any products for unique customers. A majority of its resources is used to develop platforms and products, while a portion is allocated to research and development projects. There are six platform development projects and 15 derivative projects simultaneously progressing at Organization B, which attribute to six product lines. In this case, the derivative-product project type includes the development of nine products generated from current (new) platform components as well as the sustainment of six legacy or point products. The costs associated with sustaining these point products in the marketplace are high, mostly due to the fact that they are not coherent with each other or the newer platform-based products. There are also three research and development projects. The R&D projects focus on evolving technologies for the next generation of platforms and products. A summary of the project types is found in Table 3.

Table 3 – Organization B's Project Types

Project Type	Number of Projects (estimated)
New product development for unique customer	0
New platform development for product line	6
Derivative product development for product line	15
Research and development	3

Figure 11 shows that the primary project strategies implemented by Organization B are concurrent technology transfer (60%) and sequential technology transfer (30%). In the past, the organization needed to invest more in new design projects, but do so minimally now (10%) since it already has established a current base of platforms. It also does not do much design modification (≈0%) to avoid developing variations of existing fielded products (coherence issue). Although Organization B will not modify a prior product to generate a new product, it does replace existing (legacy) products with newer products.

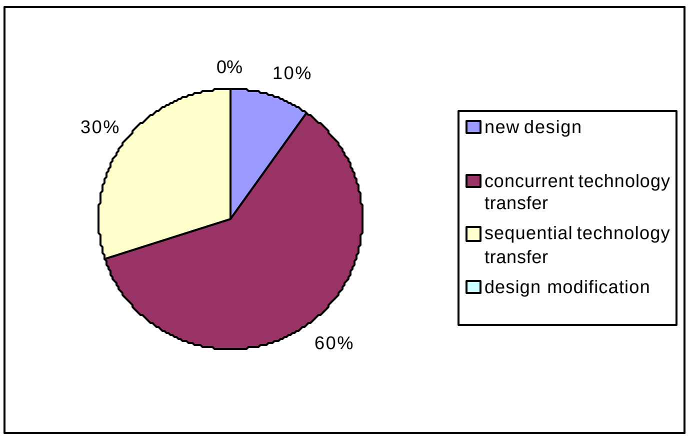

Figure 11 – Organization B's Project Strategy Utilization

4.2.1.4 Resource and Technology Sharing

Typically, it is up to management to monitor what people are doing to ensure that there is no duplication of work. Yet, at the same time, the platform strategy utilized by Organization B automatically enforces technology sharing. Several different products share platform components. Moreover, other divisions might share their platform components with Organization B and vice versa. However, sharing technologies across divisions can create problems when the two divisions do not have the same priorities. If the priorities of both divisions are not aligned, then tradeoffs may not be made with the best interest of both divisions in mind. Eventually, if not carefully managed, this can lead to the platform splitting into two different components. One manager identified this as being a problem and a risk that should be considered during the planning stage. Because the eventual split of a platform is an inefficient way to develop products, communication between the two divisions sharing the technology is critical. "Preventing this requires real discipline and top-down management," according to the manager who identified it as being a potential problem. An effective change control board can also prevent a platform from dividing into two different components.

Along with the inherent technology sharing, there is also resource sharing. The organizational structure previously described drives resource sharing. For example, the teams that design and develop the platform components are shared across projects. It is noteworthy to mention that because the product planning managers have different objectives and priorities, and employ the same development groups, there is sometimes a struggle for resources. Project knowledge and lessons learned, as forms of resources, are shared via change control board and lessons learned documentation. Although these types of information are well documented, they are not easily accessible and, therefore, not frequently used.

4.2.1.5 Incentives

Organization B recognizes that its incentives must be aligned with its platform strategy. It has a formal process that ties individual objectives back to the top five business priorities. Bonus plans are also based on the business priorities – slip rate, for example, is a bonus measure. Short-term and long-term successes are difficult to manage, however. Business teams typically influence "what" product is developed while engineering teams determine "how" the product is developed. Furthermore, the business teams have profit and loss responsibilities and incentives to deliver something in the short term while engineering development cycles are at least two years long. There is a conflict of interest here, which is not exclusively a problem for Organization B, but noticeable in most organizations.

4.2.1.6 Processes

Organization B uses a product development process that is focused on the time it takes from conception to launch a product into the market. The process documents by function what is required at each phase. Each project is assessed at every phase against the corresponding requirements and cannot advance to the next phase until meeting all of the requirements up until that point. Additionally, all project management processes are formal and documented (i.e., planning, tracking, change control, configuration management, quality assurance). Although the overall product development process works exceptionally well, two major weaknesses were identified. First, the process is predominately geared toward developing hardware. The software community has created a derivative process, but these independently developed processes do not support an overall systems approach. Organization B is currently working with a corporate engineering group to address this issue. The second deficiency associated with the development process is that it is generic for product development and not specific to platform development. There should be a procedure that focuses on platform development as well as product development. Even though these issues exist, the formal development process briefly described is successfully used not only by Organization B but also throughout the corporation.

Coexisting with the product development process are portfolio management and technology roadmap processes. These processes facilitate short-term and long-term planning – and ensure that there are research and development projects funded to support the evolution of technologies that will be used by next generation platforms and products.

4.2.2 Political Perspective

4.2.2.1 Stakeholders

There were two primary (internal) stakeholders identified for Organization B – the business teams and the development teams – although many other groups are involved in product development. There are two main business teams within Organization B (led by the product planning managers) and each has its own product strategy group. Each business team must establish strategies to achieve Organization B's business objectives defined at the division level. The development teams must produce the products that the product strategy groups identify.

The development teams, including the platform development teams, are responsible for the subcontract relationships with suppliers. There are external suppliers as well as internal suppliers (i.e., research and development group). It is imperative that the platform strategies align with the business strategies in the short term and in the long term. In the short term, the development teams must work with the suppliers to ensure that the supplier plans are aligned with the platform plans. To satisfy the long-term plans, the development teams must work with the R&D group to ensure that they are working on technologies that intercept long-term platform strategies. In the past, the business teams were more involved in product planning, but Organization B has steered away from including them because of the conflict of interest (previously described).

Because they are evaluated on “making the numbers” in the short term, the business teams tend to be very short-term focused. One manager characterized it this way, “They are tactically focused – and if you’re not careful you’ll get some tactical products that are inconsistent with the platform approach, which leads to coherence issues between the various products that you are putting out.” “Tactical products” may not be built from a reusable platform or require a feature that does not fit into the platform architecture that is evolving. Tactical products deviate from the product line or platform strategy. Both groups of stakeholders identified, the business and development teams, can influence platform and product development to some extent, yet have different priorities.

4.2.2.2 Management

Product line development is being driven from “the top” at Organization B. Management understands the necessity to implement a platform strategy to remain competitive in the market. Benchmarking companies that use a platform approach indicates that the competition is performing well in product development and delivery to the market place. Senior management believes that its platform strategy will improve time to market, productivity, coherence, and reuse. In particular, the coherence requirement is closely monitored. Management also understands, but has been slow to accept, the fact that Organization B needs to change its culture to achieve all of the benefits associated with platform and product line strategies.

Organization B is beginning to alter its methods used for planning and funding, as well as its organizational structure. In the past, when it was developing individual products, the business teams made the decisions and funding allocations. Now its product line strategy requires a strong systems engineering group and a strong platform group to provide a technical perspective and long-term strategy. Although this transition has begun, all of the details have not yet been worked out. There is still a struggle to acquire the right balance of decision making so that it does not end up with tactical point products. Continuing to allow the business teams, which have short-term objectives, to have too much power could produce tactical products. It is critical for senior management to enforce this culture change to complete the transition.

Portfolio management is a notable task at Organization B. A series of platforms, products, and, thus, product lines are mapped out in a strategic plan (i.e., goes out three to five years) that senior management reviews quarterly and updates every year. A team of senior managers (i.e., division manager, product planning managers, technology strategy managers), who have input from marketing managers and other corporate VPs, make the final decision as to what platforms and products are developed. Detailed development planning is performed by middle management (i.e., platform managers and project managers) and approved by senior management. Senior management is a strong proponent of the time-to-market or product development process and, therefore, execution of plans and project phase gates are monitored closely. Senior managers are also a significant component in setting priorities and supplying resources.

4.2.2.3 Responsibility and Accountability

The product planning managers and their business teams are accountable for profit and loss associated with the product lines and must work with the development teams to make sure that they will meet their objectives. Phase gate reviews and quarterly strategic plan reviews are implemented to ensure that the product lines are on track and still aligned with the market needs. The platform is continuously being reviewed to assure that it does not deviate from the overall product line strategy, while the projects are reviewed to warrant that they are not making changes to the platforms. Organization B tracks product line spending separate from platform spending. Organization B does not “own” the “go-to-market” channels – they are shared with the other divisions of the overall corporation. The go-to-market activities are performed by the shared sales and marketing groups and therefore joint decisions are made between Organization B and the shared corporate services.

Business teams can still compose short-term tradeoffs for product derivatives but their decisions need to be closely observed. Senior management says “what” goes into a platform, and, hence, makes the long-term tradeoffs for the platform. Maintaining coherence among products is critical; as a result, senior management and platform architecture teams make up the change control board for the platforms.

4.2.3 Cultural Perspective

4.2.3.1 Communication

Senior management circulates information about the product line strategies as well as other organizational issues. The information is, at a minimum, communicated to the platform and project managers – and then they are expected to further convey the facts to the personnel under them. There are formal meetings as well as informal meetings (i.e., e-mail, telephone, etc.) used for communication. In addition to verbal communication, project management documentation is used to keep people informed. Since Organization B is such a "process-oriented" company, documentation plays a vital role in its development. There are several graphical representations of information that are equally as important as the textual documents. For instance, the organization uses "lineage charts" and "technology roadmaps" to transmit and visualize strategies.

Because there are specific product development activities that have to be tracked and completed before the team can move on to the next phase of development, it is imperative to keep everyone informed. The product line teams (i.e., projects) meet regularly, either weekly or biweekly, to communicate project information. Individuals on a team might meet informally on a daily basis. There is no formal method for disclosing lessons learned, design decisions, etc. *across* product lines, although platform engineers might collaborate with more than one product line and, consequently, render knowledge by word of mouth. Further, platform engineers make use of a lessons learned database to capture decisions made by a particular product line so that it can be known and reused on a different product line. Finally, the product lines that pertain to the same business group can also communicate through their product planning manager, which allows for some interchange across business groups via this means. As Organization B progresses at implementing a platform strategy, formalizing a lessons learned database across the entire site will be something to address.

4.2.3.2 Resource and Technology Sharing

Similar to most organizations, Organization B has more work than capacity to execute it. The business groups have different demands – and if there is competition to get the required resources, then typically senior management allocates the resources based on business priority. In general, though, if someone is working on a platform team, then they are essentially working on every product that utilizes that platform. So inherently, there is resource as well as technology sharing as a result of the platform strategy. If, however, someone is working on a specific product team that is utilizing several different platforms, then he/she is usually just working on that product. Organization B has career development planning processes to facilitate placing people in jobs, but does not have a documented process for strategically moving people to facilitate organizational learning.

4.2.3.3 Training

Organization B does not have formal training specific to its product line development or platform strategy. Most of its training focuses on the time-to-market process and functional skills. There is no plan to incorporate platform development training per say, however, the corporation is creating a version of the time-to-market process specifically for developing platforms.

4.3 Organization C

Organization C, which develops avionics systems, was chosen to be a case study because of its platform development initiative. There is one project specifically, which will be referred to as Project X, that is implementing a platform strategy. Consequently, Project X will be the focus of this case study. Organization C is a division of a larger technology-based corporation and consists of two primary SBEs. Overall 1300 people work at Organization C; 250 of them are part of engineering and development. The following case study is based on several interviews with three employees from this avionics organization, all of whom were associated with Project X.

Although Organization C has historically developed “product lines”, they were not engineered with forethought. In other words, derivative products were not generated from a core platform, and reuse and commonality were not objectives. Even now, the entire organization is not making a transition to product line development; instead, only Project X is developing a platform architecture from which derivative systems will be created. Whether or not the entire organization would consider adopting a product line development approach (as described in this thesis) is dependent upon the success of

Project X. One of Organization C's two SBEs has approximately 60% of its market share (note – the SBE to which Project X reports), while the other only has about 10% of its market. Even though SBE1 currently has more than half the market, the organization is concerned about losing market share to competitors that are already implementing a platform strategy.

4.3.1 Strategic Perspective

4.3.1.1 Goals and Metrics

Utilizing a platform strategy was not a "top-down" decision at Organization C; on the contrary, it was a "bottom-up" initiative. The initiative was first launched in 1991 and was unsuccessful due to the organization being newly acquired by another company. After several years, the platform approach was given another chance and Project X was officially "kicked off" in December of 1998. The initiative was "sold" to senior management on analyses that showed it would help Organization C meet its fiscal objectives and stay competitive in the avionics market. Based on the financial analyses, senior management embraced the initiative and included Project X in their strategic plan. The STRAP is reviewed quarterly and updated on a yearly basis. Organization C expects to improve its bottom line through product line engineering by:

- Reducing time-to-market for new products – and, hence, increasing market share
- Increasing the margins gained on products sold – by reducing non-recurring costs through reuse
- Increasing revenues – by bringing more products to market with the same workforce

The initial plan for Project X indicated that it would take two years to develop the avionics platform and two derivative products. Estimates for derivative products suggested that they would save one-third of the typical development costs required for a new product. Consequently, their break-even point would be reached at a total of three derivative products in addition to the platform. Currently, though, Project X is behind schedule and has no software engineers working on it. Project X management is, of late, creating a new program plan, which when completed will include the 15th official timeline. In short, this project has been unstable for quite some time. It is, however, still ongoing.

Engineering management reviews Project X monthly, while senior management reviews it quarterly. There are no special "product line" metrics used to monitor Project X, just the typical financial and technical measures associated with the organization's product development process and software engineering process:

- Actual versus planned budget
- Earned value (where the project is versus the work that has to be done)
- Actual versus planned schedule (what formal reviews have been performed, what milestones have been reached, what deliverables have been made, etc.)
- Risk items (financial risks, resource risks, etc. – what are the mitigation plans and status)
- Technical risk items (what are the mitigation plans and status of the identified technical risks – also called technical performance measures or TPMs)
- Quality of software and hardware – how many defects are being found
- Review of work products – requirements, design, code (depending on the phase of the process)
- Problem reports and open issues

In a sense, the financial performance of the associated SBE is being used to measure the success of the product line engineering strategy. Albeit, it is too early in the development life cycle to quantify the impact of this initiative on schedule, development cost, and product performance in the market. The platform has not been completed and consequently no derivative products have been produced.

4.3.1.2 Organizational Structure

Organization C appears to have somewhat of a matrix organizational structure. Personnel are aligned by project and are accountable to project managers, however, personnel are "owned" by the director of engineering. It is not clear if functional managers and project managers have equal power – or which one of the two has more power. In general, Organization C does not have clearly defined leadership, which has led to confusion within the organization. It is unclear where specific responsibilities fall.

Indeed, organizational instability has been a serious problem at this company for several years. The structure for Organization C is depicted in Figure 12[7] below.

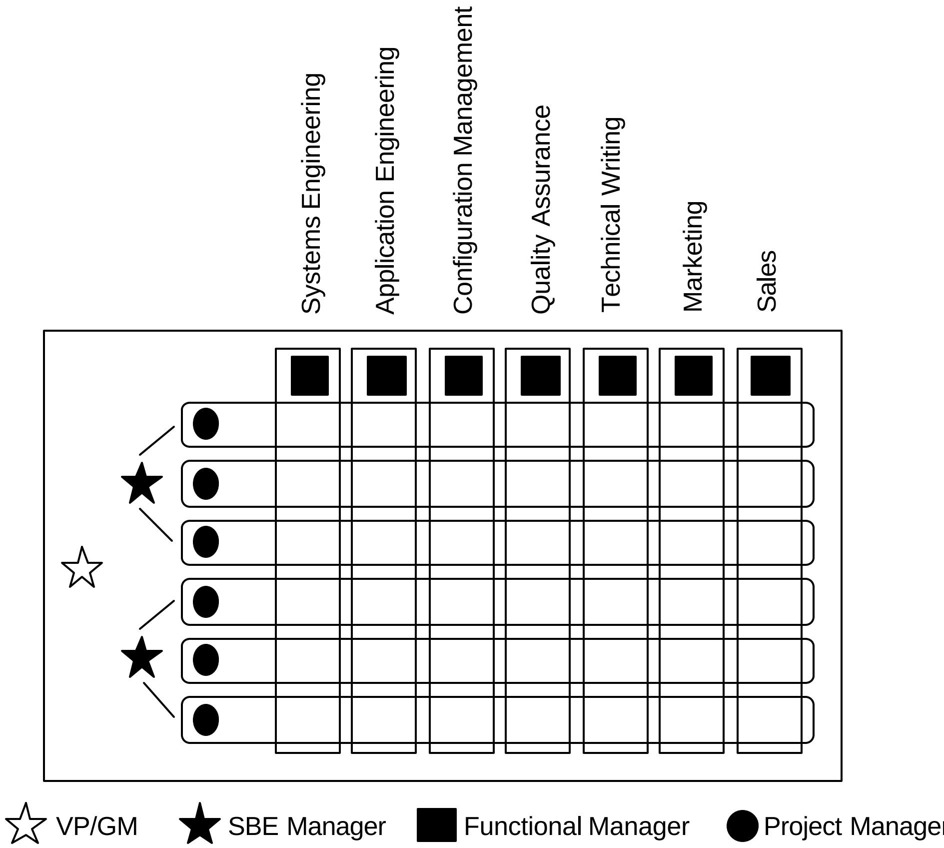

Figure 12 – Organization C's Matrix Organizational Structure

Rather than having product line managers who are accountable for platforms and derivative products, the organization has project managers who are basically responsible for the development of a single product. This has resulted in a product focus that does not support long-term planning. The functional managers report up to the director of engineering who is not shown in the figure. The project managers as well as the director of engineering report to the SBE general managers. Project X is currently the only project within the organization attempting to develop a platform for reuse.

[7] The figure may not represent the exact number of functional groups, projects, etc.

4.3.1.3 Project Types and Project Strategies

Organization C develops several avionics system components. The functionality within the products is modular, which facilitates the component-sharing and component-swapping types of modularity as well as bus modularity. In the past decade, however, this has not transpired with forethought and the organization has spent substantial amounts of money and time developing new products. As a matter of fact, the organization has had a difficult time getting new products out the door. Competitors are putting out twice as many new products twice as fast as Organization C. In the words of one manager, Organization C is "getting whipped" by its most significant competitor who is, at the most, half the size of it. The concept behind Project X is to create an avionics platform upon which various functions (i.e., an autopilot, global positioning system, etc.) can be added or eliminated to meet the prerequisites of assorted end users. The system architecture is flexible so that, theoretically, the platform will be extensible for future applications. As a result of this strategy, it is expected that the organization can get new products on the market every six to eight months, which is much quicker than what is typically achieved at this point. Figure 13 provides a graphic description of Organization C's product line concept.

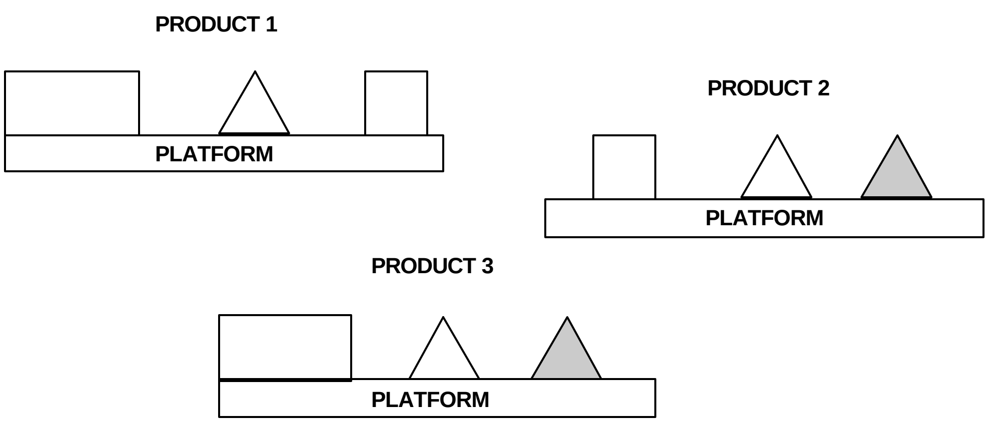

Figure 13 – Generic example of Organization C's platform strategy

Organization C, of late, implements two of the four project types previously described in Section 2.4.1.3 (see Table 4). Even though the first two derivative products have already been planned (in conjunction with the platform), these projects are not staffed and thus not explicitly under development. So, although they will have derivative product development once the platform has progressed, presently the number of derivative products under development is zero. Organization C also has two other types of projects to which it allocates resources. The first type involves "re-spinning" existing products to add features that customers want or that are already offered by competitors. The second type is referred to as "factory support" – where engineers resolve problems that arise on the production floor. Parts that go obsolete dominate factory support. In these cases, the engineer in charge is responsible for finding a replacement part or, at the other extreme, redesigning the component. These two project types are categorized as "other" in Table 4.

Table 4 – Organization C's Project Types

Project Type	Number of Projects (estimated)
New product development for unique customer	3
New platform development for product line	1
Derivative product development for product line	0
Research and development	0
Other	15

Moreover, Organization C supports products that are in the marketplace but commercially unavailable (i.e., no longer manufactured).

Organization C currently uses the new design and sequential technology transfer project strategies (Figure 14). A larger percent of their resources is applied to sequential technology transfer (73%), which includes re-spinning existing products, versus new design projects (27%).

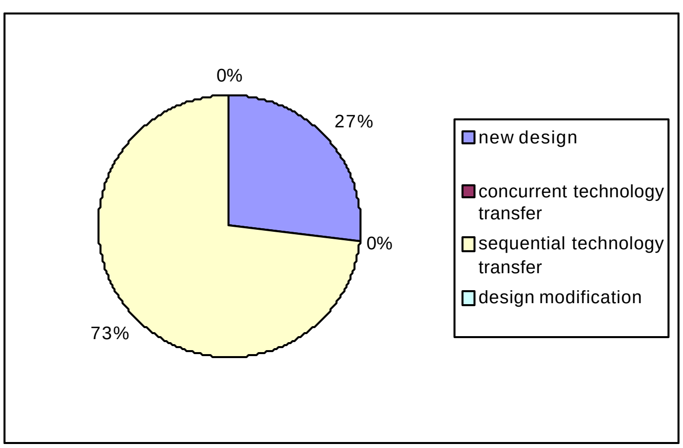

Figure 14 – Organization C's Project Strategy Utilization

The organization will begin exercising the use of concurrent technology transfer once Project X proceeds to the point where the first two planned derivative products can begin development. Typically at Organization C, “scavenging” existing products and components and reusing them is the method used to develop a new product. The difference between “what is typical” and Project X is that Project X is engineering a platform with the forethought of reuse.

4.3.1.4 Resource and Technology Sharing

Organization C does not have a formal objective for resource and technology sharing, although it has a plan for accomplishing both on Project X. Seeding the platform team on derivative product projects is involved. It is, of course, too early to know if this particular plan will be successful. Presently, organizational knowledge is shared among project teams via resource sharing (i.e., moving people from project to project). In addition, the configuration management repository, the intranet, and training are used to increase organizational learning. In general, the nature of the products allows the organization to leverage resources and technologies within an SBE as well as between the two SBEs. It is up to the project managers, the engineering manager, or the engineers themselves to recognize opportunities for resource or technology sharing. There is no formal or organized method for ensuring that the organization takes advantage of such opportunities.

4.3.1.5 Incentives

The incentive structure does not include the engineering level at Organization C; however, this lack of incentives does not prevent people from doing their jobs. Likewise, there are no specific incentives correlated with the development of the Project X product line. Senior management is primarily driven to achieve short-term objectives, which impedes the ability to instill long-term awareness in employees. Organization C has a strategic plan that maps out objectives for the next three to five years, and is reviewed yearly, but even so, it is a struggle to put actions in motion to support long-term goals. Using rational business arguments of cost reductions, employee retention, and customer satisfaction, technical management consistently reasons with senior management to incorporate long-term strategies.

4.3.1.6 Processes

Organization C utilizes a generic development process, which is comprised of several distinct phases, for its product efforts. Prior to advancing from one phase to the next, the requirements of the current phase must be met. In addition, the organization employs a software engineering process – and is currently generating a process more specific to product line development based on its experience with Project X. This will be refined over time. It is essential that formal processes for portfolio management and retaining organizational knowledge are created.

4.3.2 Political Perspective

4.3.2.1 Stakeholders

The major stakeholders involved with product line development at Organization C are the vice president and general manager of the organization and the general manager of the SBE to which Project X reports. Senior management did not initiate the product line strategy, but has been funding the project, reviewing it, and explaining to executive management of the overarching corporation why the investment is worthwhile. Therefore, senior management at Organization C has a lot riding on Project X. Technical managers who instated the platform concept are also stakeholders. Additionally, the program manager of Project X and the engineers themselves have a stake in the success of the project. Because it is still early in the development cycle and the effort is relatively subsidiary, the rest of the supply chain is currently not affected by Organization C's platform approach. Eventually, the product line could mean economies of scale for suppliers, which Organization C already uses as a negotiating tool.

4.3.2.2 Management

Typically, senior management determines what products are going to be funded with input from marketing and systems engineering. Customers have a significant influence on which products are developed; even so, Organization C does not generally develop products under a contract for a specific customer. Unfortunately, the process for making important decisions at Organization C, such as what products to develop, is essentially "broken". This is partly attributed to the fact that there has been a constant churn of management within Organization C over the past several years – the turnover has occurred so often that the instability has made it difficult, if not impossible, to follow through on strategic decisions. Equally important, senior management constantly alters project requirements, which makes execution long, laborious, and expensive. Consequently, Organization C has had a troublesome time delivering new products to the market. Most of the problems at Organization C are due to lack of management support and leadership rather than lack of engineering ability.

As previously mentioned, Project X and, thus, the platform approach, was not proposed by senior management. The concept was percolated up from technical management and it was a struggle to convince senior management to endorse it. Based on promising financial analyses, senior management included Project X in their strategic and annual operating plans. Showing support by including the project in their plans, however, has not guaranteed success. Senior management has continually changed the scope for Project X – sometimes on a weekly basis during the very early stages. Recently, senior management has withdrawn resources from the project to "fight fires" in other areas of the business. In short, even though senior management is a primary stakeholder in the success of Project X, they are not exhibiting the level of support vital for its prosperity. On the other hand, senior management of Organization C has to answer to the short-term demands made by the overarching corporation.

4.3.2.3 Responsibility and Accountability

The general manager of Project X's SBE is accountable for the profit and loss associated with Project X and, therefore, reviews the project's progress to assure that it is moving in the right direction. He reports directly to the vice president and general manager of Organization C. The program manager of Project X is responsible for ensuring that the derivative products do not deviate from the product line strategy. He utilizes several techniques to prevent any divergence or unnecessary changes. First, frequent reviews provide insight to the program so that requirements, design, and technical plans can be monitored. Second, the platform development team is part of a change control board, which maintains the platform and, thus, approves or rejects proposed changes to it. Because the platform will have to evolve over time, configuration management of the platform is critical. Finally, in the future the platform development team will be dispersed among derivative programs in order to transfer platform knowledge to the new programs.

4.3.3 Cultural Perspective

4.3.3.1 Communication

There are at least two modes of communication executed within Organization C – data communication and management communication. Data communication, a strength of the organization and culture, is conducted fairly well. This includes communication at the project level (i.e., engineers conveying technical information about the product to each other, etc.), which is achieved via formal and informal meetings, e-mail, and "cube-hopping". Data is also communicated and captured through standard documentation required by the organization's processes. Management communication, on the other hand, is not as effective. Senior management frequently announces organizational decisions, but personnel view the information rather cynically. The cynicism is mostly attributed to the lack of leadership and instability in senior management. All in all, the personnel are kept informed, for the most part, but they typically do not respond well to what they hear, especially when new senior management discloses the information.

In addition to organizational announcements, management also conducts formal review meetings. There are quarterly meetings to discuss business priorities and, typically, quarterly meetings with technical leads to discuss project performance. The product development process mandates regularly scheduled phase gate meetings, which senior management usually attends, to evaluate the progress of projects.

4.3.3.2 Resource and Technology Sharing

Organization C has what they call a "project prioritization meeting" where the program managers and senior managers gather together to assess staffing needs and capabilities. The program managers divulge "what they are doing" and "how many people are doing it" – and senior management essentially says "These are the most important projects, they will be staffed first."

Engineers at Organization C generally work on one program at a time, and like most companies, resources are scarce. Senior management recently reallocated Project X's software personnel to other programs that were struggling. Although Project

X is considered a priority, it will not provide a return on investment for several years. Therefore, senior management did not even vacillate over taking Project X's resources to staff projects that will yield revenue in the short term so that the organization can "meet its numbers".

4.3.3.3 Training

Organization C does not furnish any training on the product line methodology or the technical aspects of it. It is currently developing a course to educate its personnel on the platform and product line concepts, however. The present training portfolio covers software design methodology, software languages, system, software and hardware design tools, software test tools (informally), and corporate processes.

4.4 Organization D

Organization D, which develops a major engine accessory, was selected as a case study because it has mature platform-based product lines and processes. Organization D, a division of a larger technology-based corporation, consists of two primary SBEs that are aligned by market segment and geographically located near customers. The organization employs 5000 people; they are dispersed among various sites worldwide. The following case study is based on interviews with four employees from this organization: one from SBE1, two from SBE2 (from two different sites), plus one who oversees development in both business enterprises.

Organization D has historically used platforms to develop families of models or derivative products. However, up until about ten years ago, it did not have adequate coverage of the entire market. Past product development efforts were "single shots in the dark", meaning that it produced a system to accommodate a small range of engine sizes. There were "gaps" in the product lines and, thus, Organization D charted a plan to create an even distribution of available products. Using its platform approach was one of the key attributes of this initiative. Organization D now has approximately 55% of the market share worldwide. The next largest competitor is no more than one-half the size of Organization D.

4.4.1 Strategic Perspective

4.4.1.1 Goals and Metrics

Organization D has clearly defined strategic goals linked to the development of its product lines. The strategic plan is revisited yearly to plan the upcoming year in detail, evaluate the long-term plan, and update it. There are monthly product development reviews to assess the strategic plan as it pertains to specific projects. If a project does not appear to be aligned with the strategic plan, then the project is typically cancelled. The organization evaluates the number of products developed according to plan, and revenues realized after production, as ways of measuring the performance of its product line engineering strategy.

There are no formal metrics to measure the success of a platform in the short term. Informally, however, if one platform can accommodate more derivative products than another can, then it is considered better. The product development process at Organization D, which is renowned across the overarching corporation as the best of its type, dictates certain metrics that are assessed during project phase gate reviews. The most typical metrics are listed below:

- Actual versus planned budget
- Earned value (where the project is versus the work that has to be done)
- Actual versus planned schedule
- Technical risk items (including mitigation plans and status)
- Open/closed problem reports
- Resources consumed

The process has facilitated a reduction in development cycle time. Specifically, SBE2 has gone from a 300-week cycle time four years ago to a 150-week cycle time. The organization is still striving to decrease cycle time to less than 100 weeks. For clarification, it takes 150 weeks to develop a platform and between twelve and 36 weeks to generate a derivative product from that platform. Derivative products also require a small percent of the funds that platform products require (i.e., $10 - $600 thousand compared to $5 - $10 million). Organization D’s ultimate measure of success is whether their product is better than the competition’s.

In addition to the goals and metrics previously mentioned, Organization D has other initiatives that have been implemented in the past or are currently ongoing. One past initiative concentrated on reducing the number of parts in a product as well as reducing the total part number count. One of SBE2's systems used to have 100 parts and was quite complex and expensive to make – now that system has 29 parts and Organization D can produce it at a fraction of the cost that it formerly did. Furthermore, SBE2's part number count is down to a mere 19 unique numbers. In other words, a system may require twelve bolts, but the bolts all have the same part number, which equates to twelve parts and one part number. The organization also achieves part commonality from product to product; six different product models use one type of bolt which results in a tremendous economies of scale (i.e., they use between three and 3.5 million bolts of one part number per year). Cost reduction initiatives tie closely to these measures as well as warranty measures.

The evaluation of warranty data is an ongoing initiative. To identify how many systems have failed as well as the causes of failure, engineers review warranty returns and generate a report every month. Engineering solves the problems that correspond to the highest failure rates first. The product concept really has not changed over the past 50 years, so there has been a lot of gradual progression. Today, the organization is continuing its efforts to improve its product performance and reliability, and decrease costs, and hence, it is still refining its products and processes. It comes as no surprise that they are the leaders in their respective market.

4.4.1.2 Organizational Structure

Organization D's structure can be considered a market-aligned semi-center organization. The semi-center organization is clustered by size of the system (i.e., small and large), where the size corresponds to a particular market segment. Within a center, or an SBE as Organization D refers to them, personnel are aligned functionally and only report to a functional manager. Although the personnel are assigned to programs, they are not "owned" by program managers. Instead, they provide a service to program managers. Program managers, who are accountable to senior management, plan and execute projects but do not own resources. The heads of the

SBEs direct the functional managers to supply their resources to the various programs. The organizational structure can be seen in Figure 15.[8]

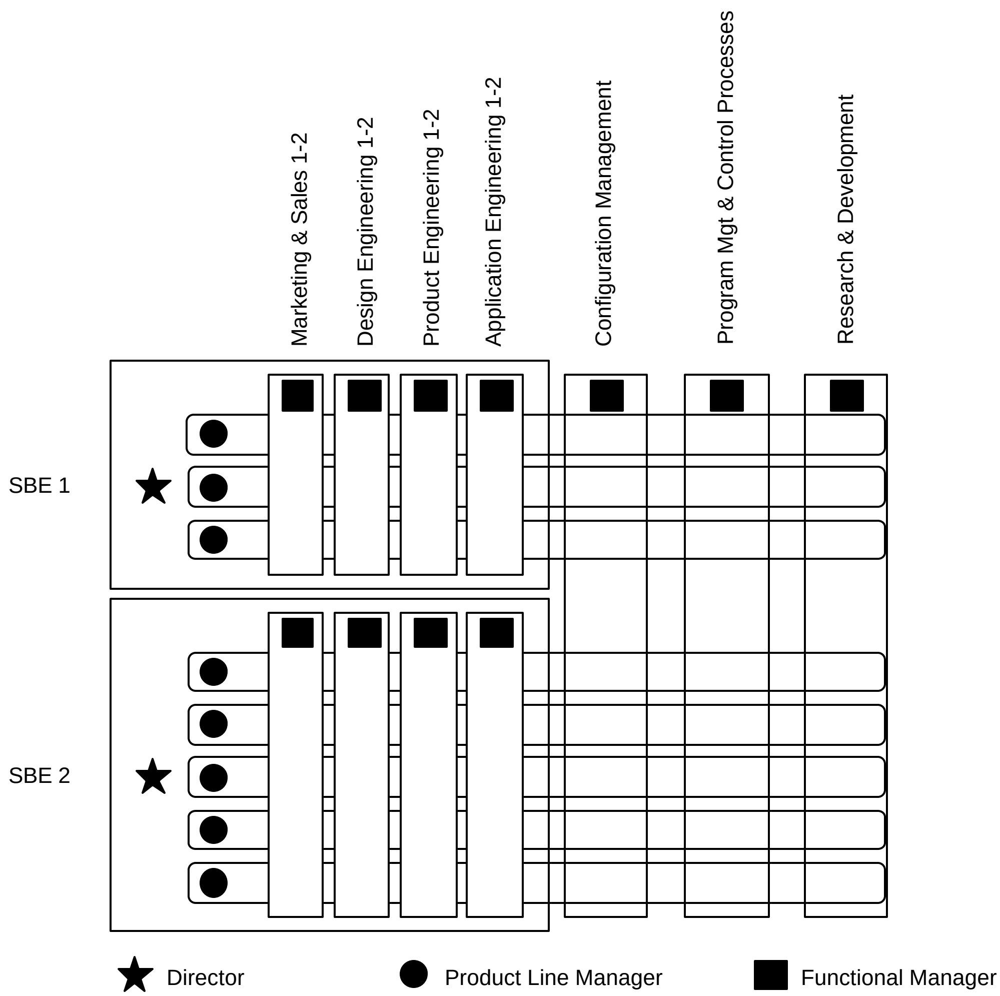

Figure 15 – Organization D's Semi-Center Organizational Structure

4.4.1.3 Project Types and Project Strategies

Organization D basically develops one type of product that meets the needs of several markets. The product is scaled to produce several individual product lines that are grouped by size. The system architecture is somewhat modular with the platform component performing the same function in every product. In short, Organization D primarily utilizes the component sharing and fabricate-to-fit types of modularity. One

[8] The figure may not represent the exact number of functional groups, products, product lines, etc.

platform size might spawn as few as two and as many as 20 derivative products. Generic pictorial descriptions of the platforms and product lines are found in Figure 16.

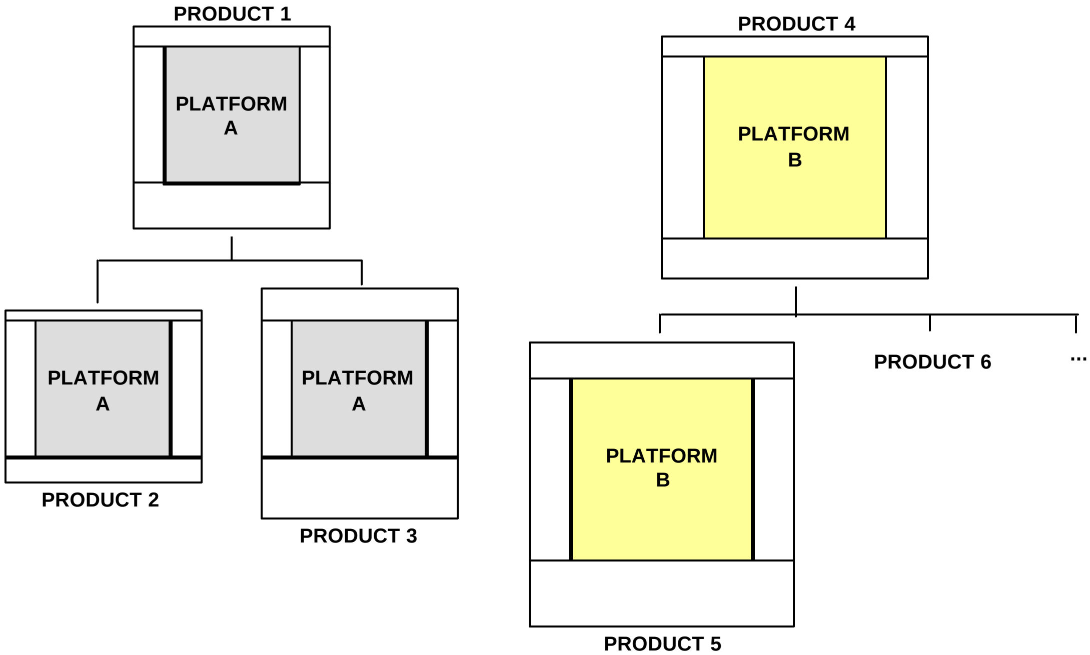

Figure 16 – Generic Example of Organization D's Platform-Based Products

SBE1 maintains three current platforms and SBE2 utilizes five current platforms from which several derivative products are generated. Moreover, they have to support over 25 years of past platforms and products. The organization does not use these outdated platforms in new products. A new platform is adopted for approximately five years to create derivative products.

Organization D utilizes all four project types previously described. Table 5 shows the breakdown of these types. Additionally, it funds a variety of other types of projects, which are categorized as "other" in the table.

Table 5 – Organization D's Project Types

Project Type	Number of Projects (estimated)
New product development for unique customer	10
New platform development for product line	8
Derivative product development for product line	24
Research and development	63
Other	400

Because, in general, there is not a great need to customize its type of product for a customer, Organization D does not have many projects classified as "new product development for unique customer". On the other hand, there are a few customers who request something specific, and, if it makes business sense, Organization D develops it. Organization D has made a business decision not to increase or decrease the size of its products beyond those currently available and, therefore, it is working to "fill in the gaps" of its product lines (as previously mentioned). As a result, there is a limited number of platform products under development, where each platform generates an average of three derivative products. The organization also has many small projects ongoing in research and development. The scope of these projects is smaller than the other types of projects – and typically these projects do not develop products, but, rather, they develop technologies. The "other" category listed in the table includes several different project types with limited scope, which is why there are so many shown (i.e., 400). One type of project included in this number is "warranty updates". The scope of a project might be to change a product according to the outcome of a warranty analysis so that the product is more reliable. There are also projects that focus on finding ways to improve the performance of a current product or to manufacture the product cheaper (i.e., "improvement projects"). Lastly, "infrastructure projects" are included in the "other" category. These are projects launched to develop internal tools or improve the organization's ability to develop products (i.e., improve ability to do stress analysis).

Knowing that Organization D has so many different types of projects ongoing, it comes as no surprise that it uses all four project strategies defined earlier. The largest percentage of projects is classified as design modification (70%), followed by sequential technology transfer (15%), concurrent technology transfer (10%) and new design (5%). Figure 17 graphically shows Organization D's project strategy utilization. The design modification strategy embodies most of the projects listed as "other" in Table 5; and the new design strategy consists mostly of new product development for a unique customer and new platform development. The derivative product development projects typically apply the concurrent and sequential technology transfer strategies. Although new design projects at Organization D basically involve evolving the product technology instead of developing a completely new product, they are still the most costly to operate and thus are fewer in number. One new design project might employ a large team and run for years, while one design modification project might take one person two months to complete. Because of the substantial amount of projects classified as design modification, altogether this group of projects requires the next largest budget compared to new design. In addition, these projects simply require time and money to analyze warranty data and do research, etc. for product improvements. Since the concurrent and sequential technology transfer strategies primarily consist of derivative projects, as a group these strategies necessitate smaller budgets comparatively.

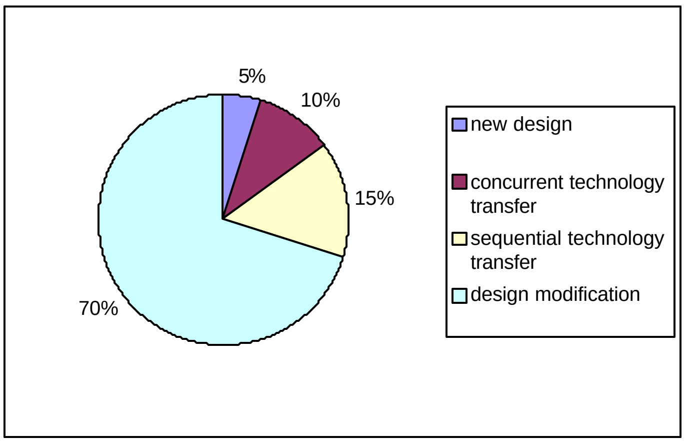

Figure 17 – Organization D's Project Strategy Utilization

4.4.1.4 Resource and Technology Sharing

By organizing the product lines into SBEs based on a range of product sizes, the organization can systematically share resources, components, and technologies *within* an SBE. The facts that product sizes differ and geographic locations differ make it physically difficult to share components and resources *between* SBEs. However, Organization D can share technologies between SBEs, since the product concept is the same. For example, the original product lines existed in one size range (i.e., large) to which SBE2 catered. When there became a demand for major engine accessories in another size range (i.e., small), Organization D was able to capture a significant portion of the market by scaling their existing product lines from large to small. They had already developed the technologies needed before the competition even had a chance. Organization D has worked hard to standardize components within SBEs and continues the effort. They have achieved approximately 90% shared components within an SBE, which means that derivative products require a minimal amount of additional work.

The product line directors oversee all of the development within an SBE. If a product line director recognizes an opportunity for a technology or component to be shared, then he will verbalize it in the monthly product development review. These reviews include participants worldwide via teleconferencing and are considered very effective by senior management as well as engineering management. Together with these monthly reviews, the organization uses technical reports and design reviews to capture and share knowledge between projects.

4.4.1.5 Incentives

Because the derivative products generated within Organization D are such a small amount of work compared to the development of a platform, the deliveries of these products are not major milestones. On the other hand, the release of a product platform is a major milestone. Therefore, the long-term success of a platform is inherent in the culture – they must develop the platform prior to the derivatives. When the platform is planned, a minimum of three derivatives is also planned. So, the short-term success of the derivatives is expected. The organization closely monitors the progress of platform and derivative development to ensure long-term and short-term success.

4.4.1.6 Processes

The product development process that Organization D has implemented, including phase gate reviews, has shown advancements in several areas. For example, the process has facilitated allocation of resources, increased project visibility to senior management, and emphasized more rigorous planning and execution. The process has also allowed Organization D to significantly reduce development cycle time, which was specifically mentioned in a previous section. One manager said, "The product development process works because we have the infrastructure support and leadership support we need." He also stated that the organization has a "zero-tolerance policy" for people who try to "go around" the system. For example, funding can be cut off if a program does not comply with the process. The product development process serves an important function at Organization D – it is the method by which projects execute plans as well as the mechanism by which management monitors progress.

The product development process addresses product line development. New projects are constantly reviewed against the product line strategy. In one of the initial meetings, it is important for the program manager to show senior management where the new product fits into the current product line to ensure that it is expanding the portfolio and not overlapping with current products. The organization also has an independent process that forces it to regularly review and manage its portfolio of products. Likewise, this process helps steer its development efforts. For instance, a "gap" in the market coverage was recently identified, which the organization is now working to "fill". The formal product development process has identified weaknesses in the program management and cost tracking processes. The organization is currently working to strengthen these particular processes.

4.4.2 Political Perspective

4.4.2.1 Stakeholders

Organization D has various internal and external stakeholders. The directors of the two SBEs have a stake in the success of the products because they are individually responsible for profit and loss. All of the personnel employed by Organization D are actually stakeholders – their jobs are dependent upon product success within the market. Externally, the customers are major stakeholders because they use Organization D's components in a product that is then sold to their customers. In a sense, the customer's success is directly dependent upon Organization D's products, and, for this reason, Organization D's customers have input into the product development phase. In turn, Organization D must work closely with its suppliers to ensure that it is designing something that can be efficiently manufactured by the suppliers. As Organization D improves its product line capabilities, there are opportunities for the organization and its suppliers to achieve economies of scale. Ultimately, Organization D's shareholders are stakeholders – their money is at stake.

4.4.2.2 Management

As previously mentioned, Organization D has historically utilized a platform approach and senior management has driven continuous improvement projects over the years. Thus, an attribute of Organization D's success is its strong senior management leadership and involvement. For example, one reason that Organization D's product development process is so successful is that the process emerged from a senior management initiative, which they continue to strongly endorse. The President of Organization D does not miss phase gate meetings. He has an intense interest in understanding the status of the projects that he has funded. The success and growth of the organization is largely accredited to its leadership.

Product development has a strict annual planning activity that is reviewed by the SBE directors, the VP of engineering, and the president of the organization. There are product development (i.e., phase gate) reviews with senior management throughout the year. In addition, there are other regularly scheduled meetings between senior managers. The VP of engineering meets with the directors and program managers every other month, while the president meets with the VPs and directors every quarter. There are also weekly staff meetings for senior management. Additionally, management is interested in hearing what the rest of the personnel have to say. In order to communicate any issues, there are monthly meetings between the technical personnel and the directors.

The president and his staff (i.e., VPs and directors) make up a committee that is responsible for reviewing the “development pipeline” and approving new projects. A specific marketing group, that collects information worldwide, assesses the potential for a product, how the organization compares to the competition, and the strategic and commercial value of the proposed product. Based on this information, as well as input from engineering, the committee, rather than one individual, resolves whether or not to pursue the project. Once a project is approved for funding, substantially more personnel get involved with planning it. Program managers primarily plan new projects, but, several engineers and functional managers are also engaged in the activity. The program managers also pull together the quality, purchasing, and manufacturing disciplines to assure that they are aligned and that each knows what is coming down the line. Then, the committee reviews the approved programs periodically to ensure that the products are still aligned with market needs. Depending on the program, these reviews can occur as regularly as monthly or quarterly. The committee is not only interested in tracking the technical progress, but is also interested in knowing the current financial forecast, project volumes, manufacturing site, customer status, issues, etc. Although senior management support for product line development is apparent, engineering is still given a limited budget, which some personnel believe is not sufficient.

4.4.2.3 Responsibility and Accountability

Profit and loss are tracked for each manufacturing plant within Organization D; therefore, the general managers of the manufacturing plants are accountable for profit and loss of the product lines. If a general manager receives direction to manufacture a high-cost product with a lot of different part numbers or total parts, then he is responsible for contacting the engineering facility to discuss cost-reducing design changes. Although accountable for generating a profit, the manufacturing plant GM does not own engineering resources (i.e., they do no report to the GM). Typically, however, manufacturing is involved early in the development process in order to mitigate a situation like that described.

The product engineering group is liable for ensuring that the derivative products do not deviate from the product line strategy. They maintain control of design drawings and review requests for new components. Only product engineers can design new core components. Organization D takes the number of unique part numbers utilized in its products very seriously – a proliferation of part numbers could result in less profitable product lines. Of course, sometimes there are advantageous reasons to change or create a new part. In addition to using common parts, Organization D also strives to maintain common manufacturing processes for different product models. The manufacturing plant GM is also responsible for working with engineering to achieve this objective. Common manufacturing processes reduce the amount of down time between production changes.

4.4.3 Cultural Perspective

4.4.3.1 Communication

Communication within specific sites, as well as among the different sites of Organization D, is rather effective. There are a number of regularly scheduled formal meetings (described in the *Processes* and *Management* sections above) in addition to several informal methods (i.e., telephone, e-mail, etc.) utilized for communication. Organization D inherently knows that it is important to keep the personnel informed. As a matter of fact, minutes are taken at the quarterly communication meeting and circulated via bulletins and e-mail to ensure that those not present receive the information shared at the gathering.

Communication among a product line team typically occurs via face-to-face meetings, which could transpire formally or informally (i.e., “cube-hopping”). People generally agree that it is the best way to communicate. Of course, telephone calls and e-mails are also commonplace among people. There are also regularly scheduled, monthly, videoconference meetings to connect the engineering groups located in different regions around the world. Although having sites dispersed globally has its challenges, Organization D has a market advantage by being located near its customers. Furthermore, the videoconferences have proven very effective and more beneficial than the participants initially thought they would be. Action items are captured during videoconferences and later driven to closure – and minutes are recorded for later communications as well. Lastly, there is, occasionally, a transfer of personnel from site to site, which facilitates communication to some extent. First, it is important to note that there are significant cultural and lingual differences between sites. Therefore, personnel at SBE1 that have experience working at SBE2 and living in its respective country, can really bridge communications between the two sites. Additionally, if people at SBE1 know people at SBE2 on a personal level from past work experiences, then this can also ease communication between the two sites.

Organization D documents the work it’s done. For example, test results, trade studies, and decisions are documented because over the years the explanations can be lost. Reports are orderly ways of ensuring that the logic behind decisions is maintained. Most documentation can be easily accessed via the organization’s intranet. The program managers of large programs maintain a “project book” which contains design review information, action items, etc. The product development process, including documented formal procedures, also dictates that certain information be documented and maintained by the program.

4.4.3.2 Resource and Technology Sharing

Most product engineers at Organization D work within one product line at a time. This means that they might work on the platform product or any of the derivative products doing a *variety of tasks*. On the other hand, some engineers perform the *same specialized function* on several different projects that could span across platforms and the corresponding product lines. Both of these circumstances facilitate resource and technology sharing. Typically, Organization D has more work to do than it has people to do it. Therefore, it is a matter of prioritizing the work to be accomplished and allocating the resources accordingly. Management recognizes that some personnel can juggle several jobs simultaneously without a problem, while others cannot feasibly do so. They take these constraints into consideration when planning programs and try to route people in the right direction. Each situation is a little different and, hence, a challenge.

Lessons learned are disclosed internally at weekly staff meetings and across different sites at the monthly videoconferences. Technologies can also be shared during these meetings. In addition, moving people from site to site circulates the technology and knowledge acquired by specific groups. Most people are willing to share their knowledge and experiences, while others prefer to keep to themselves. Sharing knowledge is encouraged and almost expected by Organization D, and, therefore, at a minimum, the knowledge is communicated verbally. Most management enforces more formal documentation of newly acquired knowledge in the form of engineering reports. Available on the organization's intranet site, these reports are the most formal method of technology sharing (including lessons learned) that Organization D utilizes.

4.4.3.3 Training

Organization D does not provide training specific to product line engineering – it believes that there is no need for formal education of this type because product line development is part of the culture. There is mentoring within the groups, however. Inexperienced employees are given positions with less responsibility until they become familiarized with the product lines; then they are put in positions of increasing responsibility to continually expand their knowledge. Moreover, rookie employees go through orientation training, which covers general product standards. The organization provides function-specific training to its personnel throughout the year as well as instruction on corporate processes.

5.0 Results and Discussion

The case studies were analyzed on a point-by-point basis. The organizations were compared strategically, politically, and culturally – and then, within each perspective, they were compared by characteristic. Observations were made in the following manner:

- What characteristics are different? Unique? Similar?
- What characteristics attribute to successful product line engineering efforts?

5.1 Observations

Preliminary observations were made in an attempt to quantify the level of success each organization has had and then to identify the organization(s) that will be used as a standard for comparison. Below, Table 6 summarizes some of the data gathered for each organization studied.

Table 6 – Summary of Data for Each Organizations Studied

Organizational Data	**A**	**B**	**C**	**D**
Time Implementing PLE (years)	10+	4	2[a]	10
Market Share (%)	75[b]	94[c]	60[b]	55
Overall Size (no. of people)[d]	5500	2000	1300	5000
Number of Platforms	5	6	1	8
Number of Derivatives	12	9[e]	0	24
PLE Ratio (Derivatives/Platforms)	2.4	1.5	0	3
PLE Cycle Time Ratio (Derivative Cycle Time/Platform Cycle Time)	0.25	0.5	0.35[f]	0.24

[a]The organization is approximately two years into its second attempt to develop a product platform.
[b]Market share for largest and most successful SBE at organization.
[c]Market share of most competitive market segment.
[d]Overall size of organization is estimated.
[e]Does not include the six legacy or "point products" that the organization is currently sustaining.
[f]Derivative cycle time is projected to be 36 weeks while platform cycle time is projected to be 104 weeks.

First, it is worthwhile to examine how long these organizations have been implementing a PLE strategy in order to put their efforts in perspective. Both Organizations A and D have been developing derivative products from platforms for *at least* ten years – that is more than twice as long as Organization B and about five times longer than C (note, however, that Project X is Organization C's second attempt to utilize PLE). It can be inferred that Organizations A and D have continuously improved their methodologies and processes over the years and have something to offer other organizations in the way of lessons learned. Also, referring back to the case studies, Organizations A and D compete in industries that almost dictate a PLE strategy. Nonetheless, this first observation implies that Organizations A and D have more experience with PLE than Organizations B and C.

Next, observing the market share possessed by each organization is an indicator of product success in general. Organization A's largest and most successful of three SBEs has 75% of its market share, while Organizations B and D have 94% and 55%, respectively. Organization A's other two SBEs hold 30% and 22% of their market share. Organization C's SBEs have 60% and 10% of their respective markets. The organizations with more PLE experience, A and D, have maintained and even gained (see Organization D case study) market share with a platform approach. Although Organizations B and C currently have the majority of their particular markets, it could be eroded by potential competitors implementing PLE efforts of their own. Organization C is already concerned about losing market share to competitors that are presently using a platform strategy. This observation, if nothing else, shows that each organization has had success with its products in the market.

Comparing their relative size puts the four organizations studied in context. Organizations A and D are more than twice the size of Organizations B and C. Accordingly, it might be expected that A and D have at least twice as many platforms and derivative products as B and C. On the contrary, because each organization produces a different type of product, this cannot be insinuated. For example, Organization A's "platforms" typically encompass the entire product, while Organization B and D's "platforms" are components within their products. Comparing Organizations B and D in this light, B is a little less than half the size of D and has a little less than half as many derivative products. The differences in platforms and products make it difficult to directly correlate size with number of platforms and derivatives for any other organizations. Other observations can be made, however.

Observing the ratio of derivatives to platforms for each organization can provide an interesting comparison. In general, a "PLE Ratio" greater than one is an indication that the organization is implementing PLE with some success – there is at least one derivative per platform. A ratio much greater than one is even better, while a ratio of three and higher would seem to be exceptional. A PLE Ratio of three means that, on average, an organization can spawn three derivative products per platform. The larger the PLE Ratio, the more derivatives per platform an organization is generating. Organization C has a PLE Ratio of zero because, unfortunately, it has not begun developing any derivative products. Organization B's PLE Ratio is 1.5, where Organization A's is 2.4 – both showing successful efforts, perhaps A more than B. Even more so than A and B, Organization D has a PLE Ratio of three. Organization A should not be discounted on the numbers alone however, because product complexity could again be an issue. Potentially, there are many other extraneous variables that could influence the PLE Ratio, such as the industry. All in all, this observation demonstrates that the best organizations studied, Organizations D and A, had ratios between two and three and, thus, have successfully derived products from platforms.

Another observation along these lines is taking the ratio of the time to develop a derivative to the time to develop a platform. This "PLE Cycle Time Ratio" could also indicate the relative level of PLE success for an organization. While a larger PLE Ratio is better, a smaller PLE Cycle Time Ratio (CTR) is preferable. A PLE CTR of one means that it took, on average, just as long to develop the derivative as it did to develop the platform. Therefore, a ratio of less than one proclaims that the organization has achieved benefits in reduced cycle time by enforcing PLE. A ratio of 0.5 means the derivatives take half the time of the platform development. Organizations A and D have PLE CTRs between 0.2 and 0.3; D has the lowest at 0.24. Again, this suggests that these organizations have saved time and, consequently, money developing products from their platforms. Organization C has *speculated* that it will only take 36 weeks to generate a derivative from the platform that it estimated would take 104 weeks to develop – giving them an estimated PLE CTR of 0.35. Note that this has not actually been achieved and the organization does not appear to be on target to achieve it. Organization B has achieved a PLE CTR of 0.5, which indicates it saves time and money with its platform approach. This observation illustrates that Organizations D and A have had more success deriving products from their platforms compared to Organizations B and C.

In summary, the following general conclusions were drawn from the observations previously described:

- Two of the organizations' product line efforts appear to be established and successful (D and A)
- One organization is working out the details and is having some success (B)
- While the final organization is in the early stages of developing a platform product (C)

Since Organization D has been doing PLE for no less than ten years, has a PLE Ratio of three, and a PLE Cycle Time Ratio of 0.24, it will be used as the standard for comparison in the following section. Organization A demonstrates slightly less yet comparable characteristics to D and, therefore, may also be used as a basis of comparison. Although Organization B does not compare quite as well to Organization D, with a PLE Ratio of 1.5 and a PLE CTR of 0.5, it has shown some success with PLE. The organization has started building support into its structure and processes to facilitate PLE, similar to Organization D, and these attributes will be apparent in the following discussion section.

5.2 Discussion

This thesis focused on the non-technical characteristics of an organization that impact product line engineering strategies.

5.2.1 Strategic Perspective

Goals: All of the organizations have strategic plans in place that project at least three to five years into the future. These plans are reviewed periodically (typically quarterly) throughout the year and updated on a yearly basis. All of the organizations, with the exception of C, have "clearly defined" strategic goals relating to the development of platforms and/or product lines. In other words, the product line engineering objective of D, A, and B is an organizational initiative embodied by all of the development projects, unlike C, whose platform efforts are isolated on a single project. In addition, Organizations D, A, and B have communicated their strategies to the personnel and, thus, it appears that the "platform concept" is well known and understood by most. At Organization C, on the contrary, the platform concept is confined to one project. Comparing the four organizations on the strategic goal aspect indicates that organizations D, A, and B have been successful when enforcing their platform and/or product line strategies at an organizational level.

Metrics: Organization D closely monitors its projects in respect to its strategic objectives. If a project does not maintain alignment with the strategic plans, then it may be cancelled. The organization also has a "zero-tolerance policy" for projects that do not adhere to the documented processes. Organization B does something somewhat similar – if a project does not meet the organization's coherency requirements, then the project does not "pass" its phase gate review. The notion of having "enterprise coherence" is a unique attribute among the organizations studied. Organization B has a rigid attitude about its products meeting the established coherence requirements. The requirements create a commonality among all of the products – reinforcing the product line strategy while generating a consistent presence in the market. The requirements are also a way of measuring platform or product line performance and, therefore, could be considered a metric. In general, all of the organizations described typical product development metrics. These "typical" metrics are listed, not shaded, in Table 7.

Table 7 – Metrics Used by the Four Organizations Studied

Metric	A	B	C	D
Actual versus planned budget	x	x	x	x
Actual versus planned schedule	x	x	x	x
Cycle time	x	x	x	x
Risk items and mitigation plans	x	x	x	x
Quality/defects found/rework	x	x	x	x
Number of problem reports (open/closed)		x	x	x
Maintenance cost		x		x
Amount of technology sharing	x			
Extent to which a product meets established coherence requirements		x		
Number of derivative products a platform can generate				x
Amount of unique part numbers				x

The metrics that are unique to a particular organization studied may serve to measure platform and/or product line performance (shaded metrics in Table 7). Note that even though these shaded metrics were described during the study, none of them were recognized as being used specifically for product line engineering. Organization D uses two uncommon metrics that potentially reinforce PLE, while both Organizations A and B identified one each. It is possible that the use of untraditional metrics, which consequently corresponds to PLE, is a result of process maturity. Organizations D appears to have an intense process focus and potentially high process maturity. Organization C did not specify any metrics out of the ordinary that could potentially fortify its platform approach. This summary demonstrates that the organizations with proven success (based on observations made in previous section) in PLE have implemented untraditional metrics as part of their development efforts.

Organizational Structure: Before a comparison of organizational structures can be accomplished, it is important to point out the size difference between the four organizations studied. See Table 8 below.

Table 8 – Organizational Structure Comparison

Organization	Estimated Overall Size	Organizational Structure
A	5500	Center
B	2000	Functional
C	1300	Matrix
D	5000	Semi-Center

Overall, Organizations D and A are more than twice as large as Organizations B and C. Indeed, it appears that the size of the organization has an impact on the structure implemented, which supports the results of Nobeoka and Cusumano's previously mentioned study [1]. The larger organizations can better tolerate organizational redundancies and, hence, maintain center or semi-center structures (note that there is not much difference between center and semi-center structures as can be seen in Section 2.4.1.2). The smaller organizations studied (i.e., B and C) use the functional and matrix structures, respectively. From this angle, it seems that Organizations B and C do not have similar structures compared to the more experienced Organizations D and A. However, the comparison is not that straightforward and, in actuality, the organizational structures of B and C may be more similar to D and A than they first appear.

It is interesting to observe the organizational structure of just one center or semi-center within Organizations D and A. One center or semi-center of these organizations is more comparable in size to Organizations B and C. When the four organizations are compared in this manner, they appear to have less variation in organizational structure. Both Organizations D and B implement a functional structure while both A and C maintain a matrix structure. Table 9 summarizes these comparisons.

Table 9 – Organizational Structure Comparison Based on Similar Organizational Size

Organization	Organizational Structure
SBE-Level of A	Matrix
B	Functional
C	Matrix
SBE-Level of D	Functional

Interestingly, Organization B is actually one part of an overarching semi-center organizational structure and, if compared at this level, it is quite comparable to Organization D. It is not clear whether Organization C, too, is actually part of an overarching center or semi-center organization. From this angle, there is less variation among the four organizations structurally. In spite of that, more observations can be made.

Organization D and A's semi-centers and centers cluster around products for particular market segments that utilize similar platforms. It appears that Organizations D and A can readily leverage resources and technologies within SBEs using these types of structures. The same could be said for Organization B and its overarching organization. Both the semi-center and center structures support the development of product lines for these organizations. At the lower level, it is not apparent why D uses a functional structure while A uses a matrix. Although personnel report to – and are evaluated by – both project and functional managers at Organization A (a matrix characteristic), they are owned by the functional managers (a functional characteristic). In a sense, Organization A also operates with a functional structure, like D, even though it is characterized as a matrix organization. The same type of convoluted matrix structure exists at Organization C, where resources are "owned" by the director of engineering. Only considering Organizations D and A, it appears that both functional and matrix structures support a PLE strategy. Perhaps this indicates that successful PLE efforts are not associated with a specific organizational structure – or considering Organization A and C's ambiguous matrix/functional structures as well as Organization

B's functional structure – perhaps this shows that functional structures more often support PLE efforts.

If it is in fact true, that successful PLE efforts are not associated with a specific organizational structure, then it is conceivable that management can use its chosen structure to further support its strategies. Based on the four organizations studied, it seems that strong leadership is necessary to clearly define organizational structures that enforce their strategies. Organizations D and A support this statement. Similarly, Organization B utilizes its functional structure to supplement its top-down platform strategy (see resource and technology sharing discussion later in this section). On the other hand, Organization C may not have the level of leadership necessary to use organizational structure as a support tool for a PLE strategy.

Project Types and Project Strategies: Observing each organization by project type does not yield much variation, but comparing by project strategy does show some variation among organizations. Organizations D and A perform all four project types listed below:

- New product development for a unique customer
- New platform development for a product line
- Derivative product development for a product line
- Research and development

Both have a larger number of derivative product projects than new product developments for a unique customer, which would be expected for an organization implementing PLE. Their research and development projects feed into the other types of projects. Organization B also funds R&D while Organization C does not. Organization B executes all of the project types; except it does not develop products for unique customers, which could actually be considered a positive characteristic. By doing so, Organization B can amortize development costs over numerous customers. This fact, however, is primarily a result of product type and the industry in which it competes, rather than a result of the organization's platform strategy. Organization C has not begun developing derivative products, but will once the platform has further progressed. There are no project type observations that appear to attribute specifically to Organizations D's success with PLE. As a matter of fact, there is not much project type variation between Organizations D, A, and B – they all execute a mix of project types. It seems beneficial for an organization implementing PLE to have a mix, which at a minimum includes platform and derivative projects.

Table 10 shows the project strategy comparison for the organizations.

Table 10 – Project Strategy Percentages Based on Number of Projects

Project Strategy	**A**	**B**	**C**	**D**
New Design (% of projects)	3	10	27	5
Concurrent Technology Transfer (% of projects)	50	60	0	10
Sequential Technology Transfer (% of projects)	25	30	73	15
Design Modification (% of projects)	22	0	0	70

There does not appear to be a normal distribution of project strategies among the four organizations studied. Based on the number of projects that use each type, the organizations allocated a percent to each project strategy. For example, theoretically, six-out-of-ten projects at Organization B use concurrent technology transfer, while three-out-of-ten use sequential technology transfer, and one-out-of-ten is new design. Even though there are not equal proportions for comparison, there are some valid and interesting observations to be made.

Seventy percent of Organization D's projects are categorized as design modification, while only one other organization even uses design modification – Organization A has 22% of its projects applying design modification. This observation may be due to either product and/or industry differences or perhaps that Organization D already has a substantial platform base and has become efficient at evolving previously developed products – or both. Organization D does have a sophisticated warranty evaluation initiative (see case study) where these types of projects are classified as design modification. Although design modification may not be beneficial for all organizations, Organization D has found an efficient way to implement this strategy.

A majority of Organizations A and B's projects utilize concurrent technology transfer, while, on the contrary, Organization D only has 10% of its projects using it. According to the literature review for this study, the concurrent technology transfer strategy is the most efficient means of leveraging product development. Thus, Organizations A and B have taken advantage of an effective project strategy as part of their PLE efforts. This difference in strategies is interesting, but due to the methodology used in this study, data were not gathered to determine what this variation implies about the organizations. More variation is apparent when considering Organization C. It has no concurrent technology transfer, while almost ¾ of its projects apply sequential technology transfer. Again, although these observations are intriguing, it is not clear as to why there is such variety in strategy. It can be extrapolated that Organization C, at this time, does not have the infrastructure in place to support the more efficient concurrent technology transfer. Perhaps once the platform product has advanced, the organization will concurrently transfer the technology to the derivative products.

All of the organizations have the smallest percent of projects employing the "clean sheet" or new design strategy. However, relative to the other three organizations, Organization C has a large percent of new design – about five times more than D and nine times more than A. This type of strategy is typically the most costly. For organizations implementing PLE, it should be characteristic to see a very small percent of new design projects. There is no doubt, however, that organizations need to execute new design projects to incorporate the latest technologies and remain competitive in the marketplace. It seems like PLE organizations need to find an adequate amount of new design projects and then leverage platforms and/or components from them. It is interesting to compare the concurrent, sequential, and modification strategies to the new design strategy for each organization. These ratios are summarized in Table 11.

Table 11 – Project Strategy Comparison Ratios

Project Strategy Ratios	**A**	**B**	**C**	**D**
Concurrent Strategy Ratio $\left(\frac{ConcurrentTechTranfer}{NewDesign}\right)$	16.7	6.0	0	2.0
Sequential Strategy Ratio $\left(\frac{SequentialTechTransfer}{NewDesign}\right)$	8.3	3.0	2.7	3.0
Modification Strategy Ratio $\left(\frac{DesignModification}{NewDesign}\right)$	7.3	0	0	14.0

Since it is known that all of the organizations studied use the new design strategy, a ratio of zero means that the organization does not use the corresponding comparison strategy (i.e., concurrent, sequential, or modification). A ratio of one would mean that for every new design project there is a project using the corresponding comparison strategy. All three of the comparison strategies – concurrent, sequential, or modification – imply reuse to some extent. Therefore, it seems that an organization implementing PLE should have a strategy ratio greater than one, if, in fact, it is utilizing that particular comparison strategy. Organization D's Modification Strategy Ratio of 14.0 means that for every new design project there is approximately 14 design modification projects. Similarly, Organization A's Concurrent Strategy Ratio of 16.7 means that for every new design project there are at least 16 projects taking advantage of concurrent technology transfer. These high ratios reiterate that Organizations D and A have many projects leveraging product development, compared to projects starting on a new design. The ratios for Organizations B and C suggest that these organizations' strategies are not leveraging product development as much as D and A.

<u>Resource and Technology Sharing</u>: Observing the resource and technology aspects from a strategic perspective uncovers some compelling attributes. Organization D accomplishes resource and technology sharing in a variety of ways. First, the modular nature of its products facilitates component reuse. This is also apparent for the other three organizations studied. It could be suggested that implementing a PLE strategy is facilitated by modular architectures.

Next, Organization D takes this aspect one step further by defining goals to standardize components and parts across products and product lines. Such initiatives, that are driven from the top, reinforce technology sharing – and Organization D's efforts have been quite successful. Organization D has an inherent advantage to achieving technology sharing since most of its products are so similar and, thus, can use the same parts. An equivalent statement can be made for Organization A. Organization B's platform strategy and coherence requirements create similar results by maximizing the use of a platform component across products and minimizing the variety of components.

Another way Organization D achieves technology and resource sharing is by organizing its resources around its platforms and product lines. Organizations A and B also use similar approaches. For Organization B, the platform groups dictate sharing resources and again technologies (i.e., components) – there is no way around it. The platform teams develop a platform that will be used in several different products and they work on all of the projects that are creating these products. One platform team member at Organization B may have responsibilities for the same platform on three different projects. Although this seems like the quintessential way of achieving resource and technology sharing, it does not come without its obstacles. Occasionally, conflicting priorities among the various projects result in a struggle for a platform team member's time. Nonetheless, organizing resources around platforms appears to be an effective tactic.

Additionally, Organization D uses documentation (i.e., technical reports) and formal meetings (i.e., design reviews, etc.) to share knowledge across projects and product sites. Although Organizations A, B, and C use several forms of documentation (i.e., lessons learned database, configuration management repository, etc.), too, they also move personnel around within the organization to share knowledge. Something that Organization D employs that no other organization studied does, is designate someone to look for opportunities to share resources and technologies. This accountability can almost ensure that at least some reuse will occur. Organization C, who has not had as much PLE success as D, has not formalized many of the above mentioned strategies to increase resource and technology sharing.

Incentives: The long-term delivery of a platform at Organization D is a major milestone, while the short-term delivery of a derivative product occurs more frequently and is not considered a major milestone. Because derivative products cannot be developed without it, there is an inherent incentive at Organization D to complete the long-term objective of creating a platform. When the platform is planned, at least three derivatives are planned. The organization monitors the projects to ensure long-term and short-term progression, but it seems to be implicit in the culture. The other organizations studied do not find it easy to work toward long-term objectives. Once again, the differences could be a matter of dissimilar products and industries.

Organization A sometimes has limited visibility in the market and cannot plan too far in advance. This makes staying focused on long-term goals difficult for the organization, but it uses its yearly STRAP review as a method of revisiting them.

Organizations B and C appear to be more short-term revenue driven than Organization D, and, hence, may have more extreme short-term demands for delivering a product. The type of market in which Organizations B and C compete may account for these differences, which in turn affect product development. Their markets require products to be delivered quickly; being “first-to-market” can frequently have a significant impact on the market performance of a product. Even though Organizations B and C may be more short-term driven, they can still take advantage of PLE. There is more of a need, however, for long-term incentives at these organizations than at Organization D. Reward and recognition for the people involved may facilitate long-term commitments.

Processes: Each organization studied described a product development process (PDP) with some sort of sequential “phase gates”. Organization D attributes its process ability and maturity to adequate infrastructure and leadership support of it. Senior management has complete “buy-in” of the process and again enforces a “zero-tolerance policy” for personnel who attempt to “go around” it. Organization D’s PDP specifically addresses its product line concept by continuously reviewing projects against the strategy and also by ensuring that the new product fits within the product line, rather than overlapping with an existing product. Organizations B and C broached that their PDPs need to be tailored to specify platform and product line development. Both organizations’ PDPs appear to be adequate for product development in general and should not be discounted on the basis of this need, however. Again, there is possibly an issue of platform and product difference.

Perhaps the reason that Organization D does not need to specify a PDP for platforms and/or product lines is that it generally develops the same type of platform for every product. In turn, each product is basically the same, sometimes just differing by size (other times differing by functional implementation as well). On the other hand, Organization B develops platforms as individual components that are essentially subsystems of its overall products. The development of a platform may require extra activities (i.e., steps, requirements, constraints, etc.) to ensure its use in more than one product, while development of a product may require yet other activities. For similar reasons, Organization C may need a platform and product line specific process. Organization A attributes its product success in part to its PDP and, like Organization D, does not reveal the need for a PDP tailored for platform development. In summary, a formal PDP facilitates product development in general for the organizations studied. Two of the less experienced organizations, B and C, expressed a need for a platform and product line specific development process.

In addition to a PDP, another process was discussed with each organization – a portfolio management process. At a minimum, this type of process helps organizations analyze their current offering of products and decide which additional products would add value to the portfolio. Organizations D and B have formal portfolio management processes, while Organization C does not. Organization A identified its portfolio management process as an area of weakness and expressed a need for an improved process. Likewise, Organization C expressed the need to acquire a formal portfolio management process. A portfolio management process would be beneficial to PLE efforts, especially when planning a product line.

5.2.2 Political Perspective

Stakeholders: There was a wide variety of stakeholders identified by each organization. The bottom line is that a lot of different groups of people have a stake in an organization's profitability. This realization is not specific to product line engineering, though. Organization D does not suggest that stakeholders explicitly enable the organization to implement PLE more successfully. However, both the PLE organization and supplier-stakeholders can gain economies of scale by working with a PLE strategy. Organization D has initiatives to reduce the part number count and increase part commonality among products to achieve economies of scale – and actually has attained cost savings as a result. Since economies of scale are a benefit achievable through PLE in conjunction with supplier-stakeholders, organizations, like Organization D, should continuously be looking for similar opportunities. As a note, Organization A's RSPs are critical stakeholders, but more so to its product development in general than specifically to its PLE effort. The relationship an organization has with its various suppliers can further its product line engineering effort, and, therefore, care should be taken to ensure that both organizations' objectives are known and somewhat aligned.

Management: Another political aspect of an organization is its management. Organization D's senior management is intensely involved in its PLE efforts. The leadership it has provided Organization D has created a culture that embodies the PLE strategy. Organization A's senior management also enables the PLE approach, like Organization D, by concerning itself with strategic product line decisions as well as planning and maintaining platforms and product lines. On the contrary, Organization C does not have the level of senior management support and guidance that these two organizations display. Also, reiterating from the case study, Organization C's platform project (i.e., Project X) was a "grass roots initiative" – unlike the "top down" initiative at D. These facts may be contributing to the organization's labored completion of its platform product and concurrent derivative products. Similar to Organization D, Organization B's platform initiative is being driven from the top down, and has shown successes accordingly. Organization B still needs to fine tune some details, but at least it has its leadership enforcing the platform approach. Where some of the attributes identified in this study might facilitate but not hinder success, the author believes that lack of senior management support alone can cause the efforts to fail.

Responsibility and Accountability: The last political aspect studied herein is responsibility and accountability. Each organization has a person or group of people accountable for the profit and loss associated with its product lines. There are several responsibilities involved with overseeing the profitability of a product line. Perhaps the most important responsibility is to ensure that a platform and its derivative products do not diverge. While the Product Line Managers at Organization D oversee the product lines, the Product Engineering group is empowered with the responsibility of governing changes. Similarly, Organizations A, B, and C have a person or a group of people maintaining alignment between platforms and derivative products. At Organizations D, A, and B, this responsibility is held at a level where the manager can oversee several projects. At Organization C, it is the responsibility of the Project X program manager, who might not have adequate visibility of the derivative projects (when they begin). There is an advantage to holding this power at a higher level – sufficient visibility of associated projects. Nevertheless, each organization uses a series of formal reviews to monitor the development of the platforms and derivative products.

In addition to program reviews, there is another tactic used in support of these product line responsibilities. Again, all changes have to be approved by the Product

Engineering group at Organization D. This process keeps the products from diverging needlessly or without regard for other products in the line. Organizations B and C talked about using a change control board (CCB) specific to platforms to ensure that unnecessary changes, which might negatively impact a subsequent derivative, are not made carelessly. At both organizations, the CCBs include members, at a minimum, of the platform development team. Organization A does not use a CCB, per se, but it does maintain close communication between the platform team and the derivative teams to monitor proposed changes. These processes are crucial when it comes to preserving alignment between platforms and the products in a product line.

5.2.3 Cultural Perspective

Communication: The exchange of facts, data, etc. occurs frequently within organizations – and it is in the best interest of management to keep the personnel informed. All four of the organizations appear to have regularly scheduled formal management and program reviews to communicate information as part of their culture. In addition, they utilize other, less formal methods on a day-to-day basis, such as e-mail, telephone calls, and "cube-hopping". These findings are not unforeseen – it would be expected that successful organizations communicate well. Since it was not a focus of this study, it is not possible to quantify how well each organization communicates; however, it seems that doing it effectively has facilitated resource and technology sharing as well as cultural change. Organization D uses videoconferencing to conduct meetings across sites, which allows them to share lessons learned and possibly even new technology advances. It is interesting to note that Organizations D, C, and B referred to using textual documents to advise personnel (i.e., reports, minutes, etc.) – and that B also cited its use of graphical documents that visually familiarize its people (i.e., lineage charts, technology roadmaps, etc.). Visually communicating strategies and data is an extremely effective method for conveying where an organization is at that point and where it is heading. Two organizations, A and B, revealed that they use lessons learned databases to educate their staff, but could not quantify to what extent it was utilized. Finally, Organization A stressed the importance of co-locating project teams. In summary, effective communication can attribute to success in almost any organization and it could conceivably expedite a transition to PLE. At Organization B, where PLE is not yet the culture as it is at D, they are providing communications to educate personnel on the platform strategy.

Resource and Technology Sharing: Resources (i.e., personnel) seem to be at a minimum at each of the four organizations studied, which is not unusual for organizations these days. Because of the competition for resources, the organizations' senior management is forced to prioritize projects and allocate resources accordingly. There are formal and regular processes at the organizations for assessing the work and the priorities, and staffing the projects accordingly. By sharing resources, both Organizations D and B also share technologies. Organization B's organizational structure inherently facilitates it – defined groups dedicated to specific platforms work on every project implementing their respective platform. Therefore, the resources and the technology are distributed across the organization. This is similar to Organization D, where part of the staff performs a specialized function on more than one project. Other staff members perform a variety of tasks on the platform and/or derivative projects. Over the years, Organization D has established processes such as this to reinforce its PLE culture. It appears that Organization B is still putting the pieces in place to influence its transition to a PLE culture, which in years to come may allow them the success that Organization D has achieved.

Training: Training personnel may provide another way of expediting a cultural change, or at least reinforcing it. Yet, each organization studied does not have any instruction specific to PLE. Each organization, of course realizing the importance of educating its employees, does have functional as well as organizational processes training. Organization D believes there is no need for PLE specific training because PLE is part of its culture. In the meantime, Organization D provides new employee orientation that covers the general product standards and the product lines. It also utilizes mentoring where new employees are given positions with less responsibility until they get to know the product lines; then they are put in positions of increasing responsibility to continually expand their knowledge. Perhaps unknowingly, Organization D is performing organizational activities that reinforce its product line culture.

In summary of the cultural perspective discussion, it is difficult to assess the extent to which an organization's cultural aspects facilitate its product line engineering efforts. This is largely a result of the research methodology used for this study.

6.0 Conclusion

The overall objective of this research, to identify non-technical characteristics that attribute to successful product line engineering efforts, has been addressed and presented in this thesis. Table 12 below summarizes noteworthy and unique practices of the four organizations studied.

Table 12 – Summary of Observations

STRATEGIC	GOALS & METRICS	✰ Strategic plans clearly defined goals relating to the development of platforms and/or product lines. ✰ Metrics used that apply specifically to product line engineering. ✰ Organization-wide product “coherence requirements” reinforced the platform and product line strategy.
	STRATEGIES	✰ Product line engineering strategies were implemented uniformly across the organization. ✰ The smallest percent of projects for each organization utilized the new design project strategy. ✰ More than half the projects for two organizations leveraged product development with the concurrent technology transfer strategy.
	RESOURCE & TECHNOLOGY SHARING	✰ Organizing resources around platforms dictated resource and technology sharing. ✰ A designated person recognizes and acts upon opportunities for organizational sharing. ✰ Modular system architectures facilitated resource and technology sharing. ✰ Initiatives to standardize components and parts increased technology sharing.
POLITICAL	MANAGEMENT & STAKEHOLDERS	✰ By defining and enforcing product line strategies, senior management enabled successful product line engineering. ✰ Supplier stakeholders who had platform strategy "buy-in" furthered product line engineering efforts.
	RESPONSIBILITY & ACCOUNTABILITY	✰ The responsibility of maintaining platform and derivative product alignment was held at a high level. ✰ Change control boards composed of platform development team members, at a minimum, controlled platform architectures.
CULTURAL	COMMUNICATION & TRAINING	✰ Verbal and textual communication modes defined specifically to convey product line engineering strategies facilitated resource and technology sharing – and expedited a cultural change. ✰ New employee orientation covered general product standards and the specific product lines of the organization.

Table 12 indicates that the strategic aspects of an organization dominate its product line engineering efforts. Once again, however, this could be a result of the research methodology used in this study. Only the most obvious political and cultural aspects were observed, through a series of interviews, at the four organizations. Potentially, latent political and cultural aspects may not have been uncovered due to the small numbers of people from each organization who were interviewed. On the other hand, several strategic characteristics were identified and more easily observed within the organizations studied.

Figure 18 puts the three perspectives of an organization that were studied – strategic, political, and cultural – in the metaphoric framework of a temple structure.

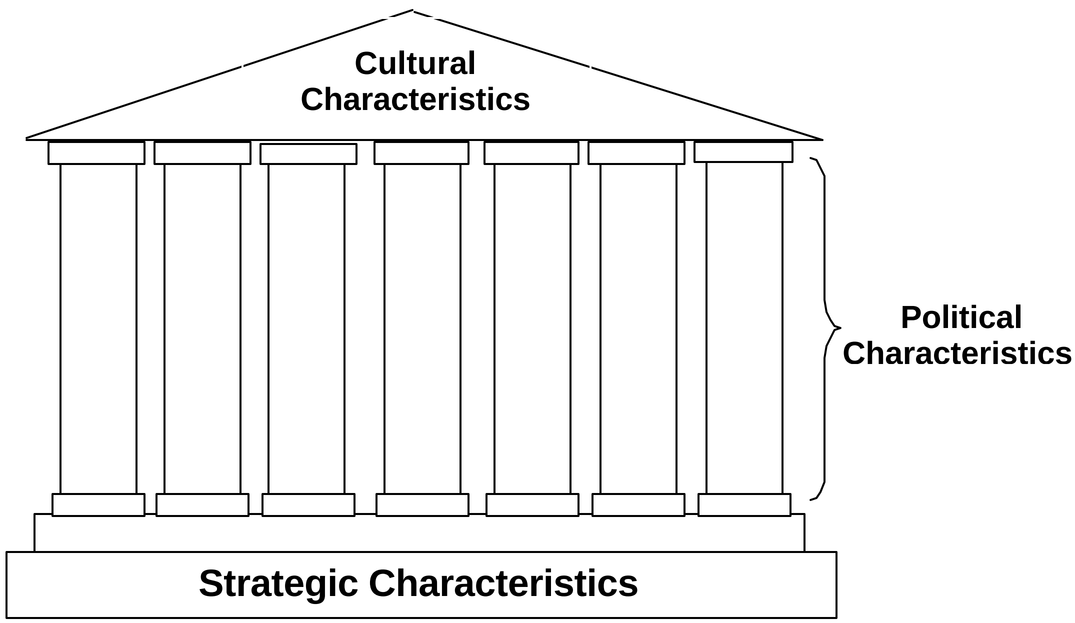

Figure 18 – Temple Structure Metaphor

The most important aspect of an architectural structure, such as the temple depicted in Figure 18, is its foundation. A solid foundation is necessary in order to build a stable environment upon it. Similarly, an organization must build up from a solid base. In other words, an organization needs its *strategic characteristics* in place to serve as the foundation from which to expand and profit. For an organization to be successful in product line engineering, it must outline strategic characteristics that will support a PLE infrastructure. Strategic goals and objectives clearly defining the vision of the organization are essential. The organization should require specific metrics to monitor and evaluate the strength and performance of its strategy so that it can adjust when necessary. Once the high-level vision of the organization is defined, then detailed project and product strategies should be established to enforce resource and technology sharing. The organizational structure used may also help create an organic foundation. Incentives and processes explicit to PLE are also strategic characteristics that may serve as substructures for organizational success.

The next element of the architectural temple, that is an integral part of the overall structure, is the support columns. The columns have a multi-functional purpose. Not only are they an extension of the foundation, creating capacity for the temple, but they also sustain the overarching structure, which is the third and last element of the temple. The *political characteristics* of an organization represent the temple's support columns. Senior management is an extension of the organization's foundation or strategy largely because it defines the foundation and must enforce it. Senior management needs to provide the power and resources to enable a product line engineering culture. Consequently, it is senior management's responsibility to furnish leadership based on its strategies that, in turn, influences the culture of the organization. Senior management is the primary link from strategy to culture.

The *cultural characteristics*, which symbolize the roofing structure of the temple, are the means by which strategies and goals are implemented and product development is executed. In order to enhance resource and technology sharing, it is essential for organizations to define verbal and textual communication modes to specifically convey PLE strategies. The culture is embodied by the organization's personnel and must be supported and empowered by management to exist. It is also in the best interest of senior management to educate its personnel. The cultural characteristics are the capstone of the temple because, in the end, it is up to the culture to implement PLE. It is likely that a PLE culture will not succeed if a strategic foundation and a political constituent do not uphold it, however. The size and capability of the temple's roofing structure is dependent on the strength of the temple foundation and support columns. Likewise, the ability of the culture is directly proportional to the strength of the strategies and effort of its management. In both instances, the three elements need to adhere together to withstand extraneous forces (i.e., nature or competition, etc.).

Based on the four case studies and the subsequent observations, the following list outlines recommendations for an organization implementing a product line engineering initiative. These recommendations are not ordered by priority, but, instead, follow the logical order of the observations listed Table 12.

- *Clearly define strategic goals and objectives for the PLE organization:* Three of the four organizations studied use STRAPs, projecting three to five years into the future, to capture PLE goals and objectives. These STRAPs are reviewed quarterly to ensure product development is on-track, and updated yearly to ensure the organization remains competitive. Organization D also enforces organization-wide initiatives that are aligned with PLE, such as reduced unique part number count. This objective further increases component commonality among products and platforms, which, at a minimum, allows the organization to achieve economies of scale.
- *Identify and utilize metrics specific to platforms and/or product lines:* The performance of organizational personnel will reflect the metrics by which they are measured, especially if there is a reward system based on the metrics. Moreover, metrics allow organizations to monitor progress, and adjust their resources, processes, etc., accordingly. Utilizing metrics that specifically pertain to PLE will reinforce the methodology. Organization D bases the effectiveness of a platform on how many derivative products can be generated from it. One example of how this metric is used is – if a newer platform can spawn more derivatives, then it will replace the old platform. Another metric that Organization D uses is the amount of unique part numbers. It is beneficial to operate with a minimal number of unique parts.
- *Enforce product line engineering uniformly across the organization:* All product development at three of the four organizations studied embodied the product line engineering strategy. On the contrary, one organization has had difficulty implementing PLE on a single isolated project. At Organization D, products are generated from a platform component. Similarly, the products at Organization B are created from a number of platforms. Developing platforms and product lines at these organizations is the norm not the exception, while at

Organization C, developing a platform is the exception. A formal process may expedite the dissemination of PLE as well as "buy-in" across the organization.

- *Vary project types between platform development, derivative product development, and research and development. Minimize customized product development unless it is part of the PLE plan (i.e., reuse is a forethought):* Organizations D and A have a larger number of derivative product projects than new product development projects for a unique customer. By implementing a PLE strategy, however, both of these organizations are better positioned to efficiently customize products for niche customers. Research and development projects at these organizations feed the latest technology advancements into the new design, platform, and derivative products, hence, keeping the products competitive.
- *Formulate a plan to apply the concurrent technology transfer, sequential technology transfer, or design modification strategies in order to efficiently leverage product development. Maintain a small percent of new design projects:* Once again, it is essential to maintain some number of new design projects in order to incorporate new technologies and market innovative products. However, an organization utilizing PLE should readily use the other project strategies to leverage the new product development. Organization D's application of the design modification strategy, in conjunction with its platform approach, makes it economical to upgrade products as per warranty data. For every one new design project, Organization D has 14 design modification projects.
- *Structure the organization and its resources around platforms to increase resource and technology sharing:* Organization B exemplifies this characteristic well – it has organized personnel into functional groups that are responsible for the development of specific platforms. Each group generates a platform (or platforms) that is used by several products. Consequently, the resources (i.e., personnel) are shared across projects as well as the technology (i.e., platforms). Organization D's semi-center structure also facilitates resource and technology sharing by grouping product lines that employ similar platforms into a semi-center.

- *Designate a person to identify opportunities to share resources and technologies across the organization:* If someone is responsible for observing product development across the organization in order to recognize opportunities to share resources and technologies, then it is more likely that such potential events will occur. Organization D has specified someone to perform this responsibility.
- *Emphasize modular system architectures to facilitate resource and technology sharing:* Modular system architectures make it easier to reuse components, and also facilitate a clear division of work. All four of the organizations studied use modular architectures in support of their PLE efforts. Organization D's modular product architecture allows it to implement one platform in many derivative products. Modularity also makes it easier to change one component, as per a warranty upgrade, without affecting the other components in the product. Organization B's modular platform approach allows it to more easily swap platforms in and out of its various products.
- *Provide senior management leadership and support for the PLE initiative:* Enforcement of PLE from the top down has resulted in successes by some of the organizations studied. Organization D's senior management employs a "zero-tolerance policy" for those trying to elude the established procedures, which could result in discipline as severe as project cancellation. In addition, the senior management at Organization D is intensely involved in product line planning and decision-making, and participates in project phase gate reviews as well. At initial phase gate reviews, project managers are required to present where the new platform or product fits into the product line. At Organization D, senior management nurtures a PLE focus.
- *Include supplier stakeholders in the PLE strategy and work together to achieve economies of scale:* Educating suppliers in respect to PLE may further an organization's level of achievable benefits. The supplier may also choose to apply PLE and, henceforth, can pass additional savings onto the procuring organization. Both organizations could achieve economies of scale by using PLE.

- *Maintain platform and derivative product alignment by giving the responsibility to personnel who have adequate visibility of the product lines:* The manager of an entire product line can oversee platform development and subsequent derivative product development to ensure they remain aligned. Organizations D and A hold their product line managers responsible for maintaining alignment between platforms and derivative products.
- *Use change control boards, which include members of the platform development team, to govern platform architectures:* Change control boards can offer many benefits to a PLE organization. First, the CCB can ensure that changes are not made to a platform that will impact future derivative products or reduce the number of potential derivative products. The benefit of including platform development team members on the CCB is that they are extremely familiar with the platform and the planned product line; they can make more informed decisions about changes to the platform. The CCB can assess the impact a platform change might have on the entire product line prior to approving a change. Another benefit of using a CCB is that it can determine when to phase in an approved change; CCBs supplement configuration management. Controlling platform products in such a manner can prevent a platform from dividing into several unique components, which defeats the purpose of the platform approach.
- *Verbally, textually, and graphically communicate the PLE vision and associated plans to develop platforms and/or product lines:* It is crucial to use all forms of communication to convey the PLE vision. It may be necessary to establish communication modes specifically for PLE. Organization B uses lineage charts and technology roadmaps to graphically transmit its platform and product line strategies.
- *Present new employee orientation to facilitate product line awareness and influence the culture. Use additional training to create PLE understanding among existing personnel:* Organization D presents new employee orientation in order to familiarize its personnel with the platforms and product lines it generates. By doing so, the organization instills the big picture in its personnel, which influences

the culture to some extent. Although this study did not identify any training used specifically to instruct existing personnel on PLE, it seems like an organization could further reinforce the strategy by educating the culture.

Once again, it appears that the most dominant factors for successful product line engineering identified by this research are the strategic characteristics of an organization. The temple metaphor suggests that the strategic characteristics are the foundation of an organization, the political characteristics are the support columns, and the cultural characteristics are the capstone. These conclusions and recommendations will be beneficial to a manager planning to implement product line engineering. This thesis concentrated on strategic, political, and cultural non-technical characteristics thought to have an impact on an organization's product line engineering efforts. The results presented support the fact that organizations need more than technical know-how to be successful – they also need organizational know-how.

Further research in this area of product development could provide additional information about the organizational characteristics associated with PLE. Several areas concerning non-technical organizational characteristics were briefly discussed and should be further investigated.

Concentrating on the political and cultural perspectives of an organization could potentially uncover obscure political and cultural attributes that contribute to product line engineering success. Perhaps this could be achieved by expanding this study to include more organizations, and, in turn, more people within an organization. Including more organizations in an additional study, for example, could identify training used to expedite a cultural change. Another approach would be to create a training curriculum for an organization planning to implement PLE; then test the curriculum on the personnel to get an idea of what types of training would be beneficial.

Another area of interest would be to study whether the size of an organization has an impact on PLE success. All of the organizations studied in this thesis were relatively large – is PLE only suitable for large organizations or can small (i.e., less than 500 or even 100 employees) "start-up" companies implement the strategy, too? A study including organizations of a smaller scale may answer this intriguing question.

Another compelling study would be to research the correlation between process maturity and PLE success. In order for organizations to collect and act upon metrics, they need to have a high level of process maturity. Perhaps effective PLE metrics stem from process maturity. Hence, further research in this area may identify a positive correlation between process maturity and PLE success.

An evaluation of metrics could also yield an interesting study. Generating extensive PLE metrics and then evaluating their usefulness by a PLE organization would, in general, further the knowledge of PLE.

There are also some areas of research that are not directly related to organizational characteristics, but, instead, technical aspects. An engaging study would be to research what type of system and/or software design methodology best facilitates PLE. In addition, it would be interesting to study what product characteristics, rather than organizational characteristics, attribute to PLE success.

The additional research described could provide large aerospace organizations, as well as the general population, with more information on product line engineering. When more attributes for successful product line engineering are understood, then more organizations will be able to take advantage of this evolutionary strategy.

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Appendix

GENERAL:

1) How many people work in your organization?

2) What type of product does your organization develop (i.e., electronic systems, digital copiers, aircraft engines, etc)?

3) Does your organization develop product lines as described in the INTRODUCTION section? If not, please briefly explain.

4) If so, would you consider the product line engineering effort successful? If so, based on what results do you think it is successful (i.e., reduced time to market from 7 to 3 years, etc) and why do you think it is successful (to what do you attribute the success)?

5) Has your organization always developed product lines? If not, how long did it take to make the transition? What was the calendar year start date and end date?

6) Why does your organization implement a product line strategy (i.e., improve time to market, industry driven, etc)?

STRATEGIC:

GOALS

1) Is there a clearly defined strategic goal linked to developing product lines within your organization?

2) How often is the product line strategy reviewed at the organizational level to ensure that the product lines are still aligned with the organizational strategic goals and the product line objectives? At the program level to ensure that the product lines are still going to meet their target markets and delivery dates?

METRICS

3) What metrics are used to measure performance of the product line engineering strategic goal?

4) What metrics are used to measure/monitor performance of a product line?

5) How has product line engineering impacted cost, schedule and product performance within your organization?

6) Identify in your mind a platform that your organization has developed. Allocate 100 engineering hours toward the development of that platform. Typically, what proportion of that effort (100 hours) did it take to develop one of the derivative products? What was the range of effort for the entire product line (for multiple derivative products)?

STRUCTURE

7a) Is there a separate entity or team that develops product lines or is it integrated throughout the organization?

7b) If separate, what type of structure does the product line team have (i.e., functional, matrix)? If integrated, what type of structure does the organization have (skip next question)?

7c) What type of structure does the overarching organization have (i.e., functional, matrix)?

PROJECTS

8) On which of the following project types does your organization work? Approximately how many of each type run simultaneously?

__ New product development for a unique customer
__ New platform development for a product line
__ Derivative products for a product line
__ Research and development
__ Other, explain:

9) How would you define your organizational project strategy (identify all the apply – see figure below for a pictorial description of each type of strategy):

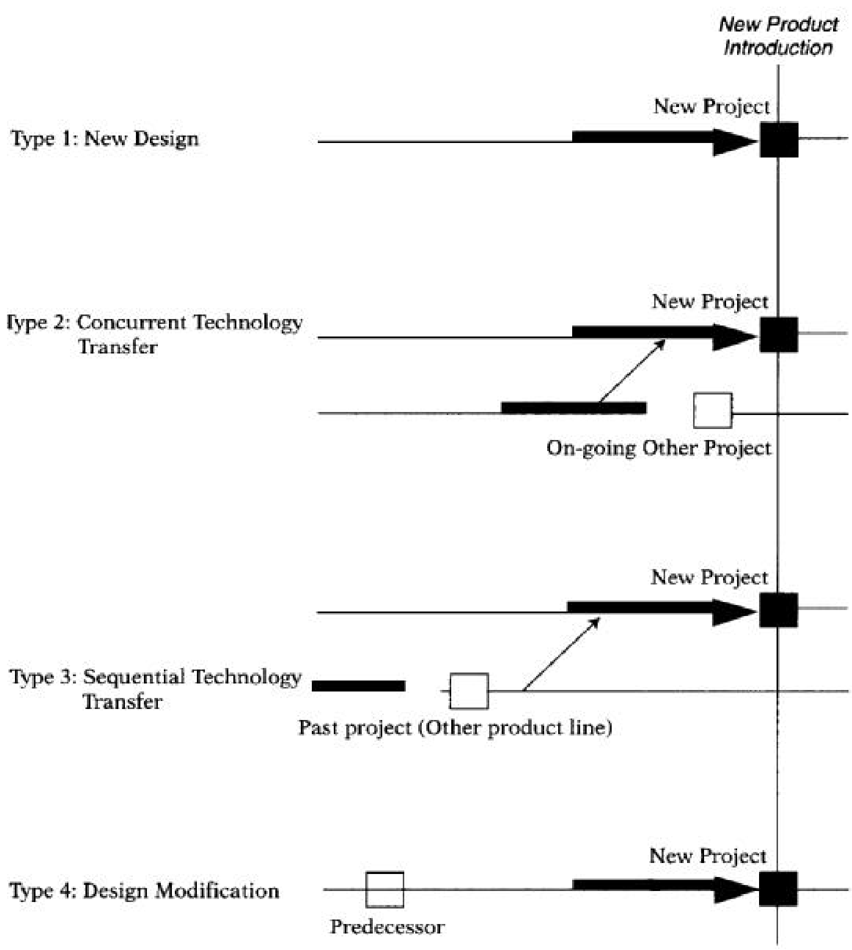
__ New Design *("clean sheet" platform design)*

__ Concurrent Technology Transfer *(new project begins to use platform from another project that has not finished its design work)*

__ Sequential Technology Transfer *(new project inherits platform from another project that has finished its design work; the new project inherits the platform "off the shelf")*

__ Design Modification *(new project inherits platform from predecessor product line)*

[Figure from Cusumano and Nobeoka's book *Thinking Beyond Lean*, 1998, p 10.]



Source: Nobeoka and Cusumano, 1995, p. 398.

10) How many product lines exist simultaneously?

11) Approximately, how long does it take to develop a platform architecture/product?

12) Approximately, how long do you use it?

13) Approximately, how many derivative products are developed from one platform (how many products in a product line)?

RESOURCE AND TECHNOLOGY SHARING

14a) How is technology/component sharing accomplished (i.e., transfer of people, organizational meetings, etc)?

14b) Do you find the identified methods effective? Why or why not?

15) How do you capture and share knowledge from one product line or program to the next?

16) What percent of the development projects share components?

INCENTIVES

17) Does the incentive structure reflect the organizational goals and structure? Are performance objectives in line with developing product lines? If so, how?

18) How do you promote short-term success (meeting derivative deliverables) while at the same time promote long-term success (delivering the product line)?

PROCESSES

19a) Is there a special (documented) process for developing product lines or is there a generic process that is used for all product development?

19b) If so, do you think that the process works? Why or why not?

20) If not, what types of processes do you think are needed?

POLITICAL:

STAKEHOLDERS

1) Can you identify the major stakeholders involved in developing product lines within your organization?

2) How do suppliers enable or facilitate product line development? What role do they play?

MANAGEMENT

3a) Is there senior management support of product line development?

3b) If so, how is the support shown (i.e., attending meetings, etc)?

4a) Who decides what product lines are going to be developed? Who has the biggest influence on new development projects (i.e., marketing, senior management, etc)?

4b) What is the lowest level of management involved in planning a product line? Are any engineers involved?

RESPONSIBILITY/ACCOUNTABILITY

5) Who is responsible for the profit or loss associated with a product line (i.e., engineering management or senior management)?

6) How do you ensure that the derivative products don't deviate from the product line strategy (or how do you ensure that a derivative product team does not make changes that impact the platform architecture or entire product line)?

CULTURAL:

COMMUNICATION

1a) Is communication considered a management priority?

1b) If so, how does management communicate this priority (i.e., meetings, performance evaluations, organizational structure, etc)?

2) Do you think that your organization communicates effectively? Why or why not?

3a) What is the main source of communication among a product line team (i.e., meetings, e-mail, etc)?

3b) What is the main source of communication between product line teams (i.e., meetings, e-mail, etc)?

RESOURCE AND TECHNOLOGY SHARING

4a) Are people willing to share their knowledge with development teams other than their own? Why or why not?

4b) Do engineers tend to work on one product line at a time?

5) How do you handle staffing continuity – moving people from one job to the next?

TRAINING

6) What type of training, if any, is or was given to your personnel in support of product line engineering?

IN CLOSING:

What issues do you have with developing product lines?